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The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Longitudinal Cohort Study of Apache AH Mk 1 Pilots – Final Report (Vision and Handedness)

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Human use

The study protocol received ethical clearance through the United Kingdom's Defence Medical Services Ethics Committee and the U.S. Army Aeromedical Research Laboratory's (USAARL) Human Use committee.

Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to Army regulation 70-25 and USAMRMC Regulation 70-25 on use of volunteers in research.

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14. ABSTRACT

The AH-64 Apache attack helicopter provides forward-looking infrared and instrumentation symbology to the pilot, via a right-sided monocular helmet-mounted display (HMD). The optical input to the two eyes differs and can lead to binocular rivalry. Several reports have identified visual issues arising in AH-64 pilots during and after flight, most commonly headaches, visual discomfort, and eye fatigue. The possible residual impact of the long-term use of a monocular HMD on visual performance has not previously been studied. This joint United Kingdom-United States study followed for 10 years a cohort of newly exposed AH-64D pilots and a control population of nonAH-64D pilots. Visual function data and subjective symptoms were collected via an expanded battery of monocular and binocular tests and annual questionnaires. Data were examined for 46 exposed and 70 control subjects. No statistically significant differences between exposed and control groups were noted for any of the visual tests. (Continued on next page.)

15. SUBJECT TERMS

AH-64, visual health, visual function assessment, monocular display, Apache, helmet mounted display

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Abstract (continued)

In-flight, headaches and visual discomfort were reported respectively by 58 and 23 percent of the control subjects, and 56 and 51 percent of the exposed subjects. The study found no significant evidence that the prolonged use of the AH-64 monocular HMD produces any meaningful differential vision changes between the two eyes, or that the visual performance of exposed subjects differed from that of control subjects.

Executive summary

Purpose and scope of document

This is the final report for the study titled *The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots*. The principal aim of this occupational health study was to determine if the use of the monocular Integrated Helmet and Display Sighting System (IHADSS) helmet-mounted display (HMD) in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual (specifically binocular) performance. Additional information concerning other unique problems (e.g., helmet usage, neck and back pain, and handedness) of the Apache AH Mk 1 aircrew was elicited as a secondary objective.[1] This study was a collaborative effort between the British Army and the U.S. Army and was conducted under the auspices of The Technical Cooperative Program (TTCP), Subgroup U, Technical Panel 7 (Human Factors in the Aviation Environment).

A cohort of British Apache AH Mk 1 pilots (exposed group) and a control group of British Army pilots, who fly helicopter models other than the Apache while wearing binocular night vision goggles (NVGs) during night flight, were followed over a 10-year period. Data were collected via annual eye exams and questionnaires.

The study protocol received ethical clearance through the Defence Medical Services Ethics Committee (United Kingdom) in January 2000. The Headquarters Director of Army Aviation (United Kingdom)[2] and the Headquarters of the Joint Helicopter Command (United Kingdom) both approved the study in 2000. The protocol was also approved by the U.S. Army Aeromedical Research laboratory (USAARL) Scientific and Human Use committees over the period of December 1999 to January 2000.

Study responsibilities were divided between two actively participating organizations: The Headquarters Director Army Aviation (HQ DAAvn), Middle Wallop, United Kingdom, and the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, United States. Subject recruitment, questionnaire administration, and eye exams were conducted in the United Kingdom by the assigned U.S. Army Medical Corps Aviation Medicine exchange officer[3] at various British Army air bases, but primarily at Middle Wallop. Data analyses were conducted at the USAARL. Reports were written jointly by the U.S. principal investigator and one or more of the Aviation Medicine Exchange Officers or British Specialists in Aviation Medicine (SAMs).[4]

A series of interim USAARL reports and professional society presentations have documented the progress of this study:

[1] Data for non-visual performance parameters, e.g., helmet use, head and neck pain, and handedness, are reported separately (Walters et al., 2013).
[2] HQ DAAvn is currently the Headquarters Army Air Corps (HQ AAC).
[3] Over the 10-year course of the study, six U.S. Army Flight Surgeons served in this role.
[4] When required by logistical issues, British SAMs conducted study functions. A SAM is the United Kingdom equivalent to a U.S. Flight Surgeon.

- USAARL Report No. 2002-04, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Initial Report."
- "Cohort Vision Study of Apache AH Mk 1 Pilots: Protocol and Methodology," SPIE, Head and Helmet-Mounted Displays VII, Vol. 4711, August 2002.
- USAARL Report No. 2004-18, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Two-Year Baseline Review."
- "Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A 10-Year Prospective Cohort Study of Apache AH MK 1 Pilots-A Four-Year Update," Aviation Space and Environmental Medicine (Abstract), 79:3, May 2008.
- USAARL Report No. 2010-09, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Four-Year Review."
- "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Study Midpoint Update," SPIE, Head and Helmet-Mounted Displays XIV, Vol. 7326, April 2009.

The current and final report presents the longitudinal data analysis for visual performance data for the full 10-year period, January 2000 to July 2010.[5] Visual performance data are examined for within- and between-subject differences for 116 subjects: 35 initially enrolled as exposed (AH Mk 1), 70 initially enrolled as control,[6] and 11 converted[7] subjects.

Subject enrollment

A total of 227 subjects were enrolled during the conduct of the study.[8] The first subject was enrolled in November 2000[9] and the last subject in July 2006. Of these, 104 subjects were not included in the final study analysis because only an initial eye examination was performed. An additional 4 subjects were disqualified for various reasons not related to the study. One exposed subject was disqualified because this subject only had acquired 1 month of Apache flight time. Over the period of the study, 13 subjects initially enrolled as control subjects entered the Apache pilot training program (i.e., converted to the exposed subject group). One subject, who initially was enrolled as a control, completed Apache training, but later left the Apache program and returned to a non-Apache flight status. Because of limited data and delays due to transitioning, it was decided to exclude this subject from the final data analysis. A second converted subject was enrolled and underwent 2 eye examinations as a control, converted to the Apache program in March 2005, and underwent a final study eye examination in April 2005, with only 1 month of exposure to the Apache's monocular HMD. It was decided to discard this subject's last exam and treat as a control subject. This resulted in a total of 11 converted subjects.

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[5] The collection of data was suspended during the first year of the study due to late delivery of aircraft, during which no Apache flight hours were logged.
[6] Control subjects flew non-Apache aircraft, e.g., the Westland Gazelle, the Squirrel and the Lynx Mk 7/9.
[7] A conversion subject is defined as an initially enrolled control subject who during the period of the study transitioned into the AH Mk 1 Apache aircraft.
[8] A total of 229 subject numbers were assigned; however, two subjects were assigned double numbers, resulting in only 227 unique subjects being enrolled.
[9] While the first subject (Subject #1) was enrolled and completed the questionnaire in November 2000, the subject's first eye exam was not conducted until March 2001.

In summary, there were a total of 116 subjects included in the final analysis: 46 exposed subjects (including 11 converted) and 70 control subjects.

Study timeline

The study was divided into five phases (table ES-1): protocol development and approval, initial documentation of the study's purpose and scope, subject enrollment, biennial data analyses and reports, and a final analysis and report.

The initial phase of the study originally was planned for 1998. However, due to delays in both the initial military airworthiness release of the airframe (aircraft) and the availability of the Full Mission Simulator, the study start was not implemented until mid-2000.

The original study design anticipated a minimum of 80 exposed and 300 control subjects by the midpoint (end of 5th year) of the study. These goals were not achieved due to a number of factors, which include previously mentioned delays in the initial fielding of the AH Mk 1 Apache aircraft, geographically dispersed subject population, and unanticipated and prolonged military actions in Iraq and Afghanistan.

Methods

A cohort of British Apache AH Mk 1 pilots (exposed group) and a control group of British Army helicopter pilots who flew aircraft other than the Apache AH Mk 1 (and wore binocular NVGs during night flight) were followed over a 10-year period. At yearly intervals, the subjects were asked to complete a questionnaire and undergo an expanded flight physical examination. The questionnaires addressed flight experience, vision history, disorientation, neck and back pain,[10] helmet usage, contact lens use, and handedness. The expanded physical examination added a battery of vision tests designed to assess both monocular and binocular visual performance to the annual flight physical. The data record form is provided in appendix C.

Summary

Tables ES-2 and ES-3 summarize the comparison between demographics, visual examination data, and questionnaire responses of the exposed and control groups for major study parameters.

Demographics

The 46 exposed and converted subjects used in the final analysis were all male (100%) and ranged in age (at first exam date) from 23 to 47 years, with a mean (*M*) and median (*Mdn*) of 34 and 35 years, respectively (table ES-2). The 70 control subjects were predominantly male (96%) and ranged in age (at first exam date) from 22 to 49 years, with a *M* and *Mdn* of 31 and 29 years, respectively. The difference between the exposed and control *M* age was found to be statistically significant ($p = 0.007$) with the exposed group being older at age of enrollment.

[10] Neck and back pain data are addressed in a separate report.

Table ES-1.
Study timeline.

Phase	Dates	Objective	Execution
ONE	1998 to 2000	Protocol development and approval	Completed 2000
TWO	2000 to 2001	Initial report – Study purpose and scope	Completed 2001; USAARL Report No. 2002-04, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Initial Report." (Hiatt et al., 2002a)
THREE	2000 to 2006	Subject enrollment	A total of 227 subjects enrolled over the period of November 2000 to July 2006
FOUR	2000 to 2008	Biennial interim reports	
	2000 to 2002	2-year report	USAARL Report No. 2004-18, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Two-Year Baseline Review." (Rash et al., 2004)
	2003 to 2004	4-year report	USAARL Report No. 2010-09, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Four-Year Review." (Rash et al., 2010)
	2005 to 2006	6-year report	"The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Study Midpoint Update." (Hiatt et al., 2009)
	2007 to 2008	8-year report	Due to loss of key U.S. personnel, an 8-year interim report was not published; a data review was performed by the U.S. Aeromedical exchange flight surgeon to fulfill duty-of-care obligations to ensure subject health and safety.
FIVE	2013	10-year final report	Completed December, 2014

Due to the very small presence of females in the study (exposed – 0%; control – 4%), the final analysis did not perform any comparisons of performance by gender.

Flight experience, based on total flight hours, was obtained via annual questionnaires. Due to geographical challenges and time constraints, there was not always a one-to-one correspondence between questionnaires and eye exams. Consequently, these data for total subject flight hours and flight hours flown during the study are underreported.[11] However, these data do provide a

[11] Flight hour data are underreported for 21% of control subjects and 17% of exposed subjects.

lower-end approximation of the level of flight experience for subjects upon enrolling in the study as well as of flight hours flown during the study.

Table ES-2.
Study demographics.

	Sample size (*n*)	**Gender**	**Age[12] (Years)**	**Total flight hours[13]**	**Flight hours during study**	**Night vision device[14] flight hours during study**
Exposed [15]	46	Male: 46 (100%) Female: 0 (0%)	Min: 23 Max: 47 *M*: 34 *Mdn*: 35	Min: 220 Max: 4,850 *M*: 2,405 *Mdn*: 2,495	Min: 45 Max: 1,810 *M*: 584 *Mdn*: 503 Total: 22,184	Min: 10 Max: 1,810 *M*: 592 *Mdn*: 500 Total: 21,892
Control	70	Male: 67 (96%) Female: 3 (4%)	Min: 22 Max: 49 *M*: 31 *Mdn*: 29	Min: 80 Max: 7,400 *M*: 898 *Mdn*: 200	Min: 30 Max: 4,050 *M*: 597 *Mdn*: 350 Total: 26,862	Min: 3 Max: 200 *M*: 49 *Mdn*: 37 Total: 2,713
Significance			**$p = 0.007$**	**$p < 0.0001$**	$p = 0.919$	**$p < 0.0001$**

Note: Bold *p*-values imply a statistically significant difference.

Total flight hours reported by control subjects (upon study enrollment) ranged from 80 to 7400, with a *M* and *Mdn* of 898 and 200, respectively. As a group, control subjects accumulated a total of at least 26,862 flight hours during participation in the study, ranging individually from 30 to 4050, with a *M* and *Mdn* of 597 and 350, respectively.[16]

For exposed (and converted) subjects, total flight hours (upon study enrollment) ranged from 220 to 4850, with a *M* and *Mdn* of 2405 and 2495, respectively. As a group, exposed (and converted) subjects accumulated a total of at least 22,184 flight hours during study participation, ranging individually from 45 to 1810, with a *M* and *Mdn* of 584 and 503, respectively. [17]

Total flight hours flown using the binocular NVGs reported by control subjects while enrolled in the study ranged from 3 to 200, with a *M* and *Mdn* of 49 and 37, respectively. As a group, control subjects accumulated a total of at least 2713 NVG flight hours during participation in the study. Exposed (and converted) subjects reported accumulating a total of 21,892 flight hours using the monocular IHADSS night vision device (NVD) during the study. These IHADSS flight hours ranged from 10 to 1810, with a *M* and *Mdn* of 592 and 500, respectively.

[12] Age data are based on age at first eye exam.
[13] Total flight hours upon entering study. These data were acquired from questionnaires, and the date of first completed questionnaire did not always coincide with date of first eye exam.
[14] The NVD is the monocular IHADSS for exposed subjects and the binocular night NVGs for control subjects.
[15] Includes converted subjects.
[16] Flight hour data not available, due to failure of subjects to complete questionnaires, were not included in statistics.
[17] Flight hour data for converted subjects were computed from date of conversion; flight hour data not available, due to failure of subjects to complete questionnaires, were not included in statistics.

The differences between the means for the exposed and control groups were significant ($p < 0.0001$) for both total flight hours at time of enrollment in study and NVD flight hours flown during the study; the difference in means for total flight hours flown during the study was not significant ($p = 0.919$).

Vision history

Vision correction

Of the 70 control subjects, 34 percent (%) (24) reported that they had been prescribed vision correction via spectacles; 7% (5) had been prescribed contact lenses. Optical correction data were available for 45 of the 46 exposed subjects; of these 45 subjects, 31% (14) reported that they had been prescribed spectacles, and 16% (7) had been prescribed contact lenses. A 2 x 3 Chi-square (2-tailed, Fisher Exact test) analysis of these data found no significant differences between exposed and control groups for proportions requiring no optical correction or wearing either spectacles or contact lenses ($p = 0.36$). See table ES-3.

Table ES-3.
Executive summary.

Parameter	Exposed	Control	Findings
VISION HISTORY			
Vision correction	31% (14) use spectacles and 16% (7) use contact lenses for vision correction ($n = 45$)	34% (24) use spectacles and 7% (5) use contact lenses for vision correction ($n = 70$)	Difference not statistically significant for distribution of visual correction requirements ($p = 0.36$)
Sighting eye preference	84% (37) right; 12% (5) left; 4% (2) bilateral ($n = 44$)	75% (49) right; 23% (15) left; 2% (1) bilateral ($n = 65$)	Difference not significantly significant ($p = 0.22$)
VISUAL PROBLEMS			
Visual symptoms	Headache (56%), visual discomfort (51%) and disorientation (36%), most frequently reported symptoms *during* flight ($n = 39$)	Disorientation (60%), headache (58%) and nausea (42%) most frequently reported symptoms *during* flight ($n = 65$)	Difference in frequencies of reported headaches not statistically significant ($p = 0.61$); however, difference in frequencies of disorientation was statistically significant (**$p = 0.03$**)
	Headache (51%) most frequently reported symptom *after* flight ($n = 39$)	Headache (49%) most frequently reported symptom *after* flight ($n = 67$)	Difference in frequency of reported headaches not statistically significant ($p = 1.00$)
Eye fatigue (Night flight)	86% (31) reported experiencing eye fatigue ($n = 36$)	75% (45) reported experiencing eye fatigue ($n = 60$)	Difference not statistically significant ($p = 0.30$)
Color adaptation	50% (19) reported experiencing post-flight color adaptation ($n = 38$)	68% (40) reported experiencing post-flight color adaptation ($n = 59$)	Difference not statistically significant ($p = 0.09$)

Note: Bold *p*-value implies a statistically significant difference.

Table ES-3 (continued).
Executive summary.

Parameter	Exposed	Control	Findings
SPATIAL DISORIENTATION			
Episodes of spatial disorientation	32% (12) reported experiencing disorientation (n = 37)	29% (17) reported experiencing disorientation (n = 59)	Difference not statistically significant (p = 0.66)
HANDEDNESS			
Edinburgh Handedness Inventory (EHI)	81% (35) right; 19% (8) left; *M* EHI = +50 (n = 43)	86% (56) right; 14% (9) left; *M* EHI = +60 (n = 65)	Differences in proportion and *M* EHI scores not statistically significant (p = 0.58, p = 0.40)
EYE EXAMINATION			
Refractive error (Spherical equivalent power)	Right eye -0.14D; Left eye -0.11D (n = 46)	Right eye -0.03D; Left eye +0.06D (n = 66)	Differences not statistically significant (Right, p = 0.37; Left, p = 0.26)
	<u>Within-subject</u> Right: -0.14D Left: -0.11D		Paired-samples t-test: Difference not statistically significant (p = 0.36)
Bailey-Lovie high contrast visual acuity (HCVA)	Right 0.07 logMAR; Left 0.08 logMAR (n = 43)	Right 0.05 logMAR; Left 0.06 logMAR (n = 69)	Differences not statistically significant (Right, p = 0.30; Left, p = 0.58)
	<u>Within-subject</u> Right: 0.07 logMAR Left: 0.08 logMAR (n = 43)		Paired-samples t-test: Differences not statistically significant (p = 0.67)
Bailey-Lovie low contrast visual acuity (LCVA)	Right; Left 0.30 logMAR (n = 43)	Right 0.26 logMAR; Left 0.29 logMAR (n = 49)	Differences not statistically significant (Right, p = 0.13; Left, p = 0.68)
	<u>Within-subject</u> Right: 0.30 logMAR Left: 0.30 logMAR (n = 43)		Paired-samples t-test: Differences not statistically significant (p = 0.83)
Small letter contrast	Right 1.02 logCS; Left 1.04 logCS (n = 43)	Right 1.05 logCS; Left 1.07 logCS (n = 63)	Differences not statistically significant (Right, p = 0.39; Left, p = 0.68)
	<u>Within-subject</u> Right: 1.02 logCS Left: 1.04 logCS (n = 43)		Paired-samples t-test: Differences not statistically significant (p = 0.67)
Depth perception	Final scores: *M* 25.9 arcsec, *Mdn* 25.0 arcsec Difference scores: *M* 2.7 arcsec (n = 45)	Final scores: *M* 26.4 arcsec, *Mdn* 25.0 arcsec Difference scores: *M* 2.0 arcsec (n = 70)	Differences not statistically significant: Final scores (p = 0.93); Difference scores (p = 0.78)

Note: Bold p-value implies a statistically significant difference.

Table ES-3 (continued).

Executive summary.

Parameter	Exposed	Control	Findings
Color perception	TES difference Right 0.67, Left -1.59; CCI difference Right 0.00, Left -0.07 (n = 46)	TES difference Right -1.77, Left -0.56; CCI difference Right -0.05, Left -0.02 (n = 70)	Differences not statistically significant: TES difference (Right, p = 0.13 Left, p = 0.50); CCI difference (Right, p = 0.40; Left, p = 0.36)
	Within-subject TES: Right 6.86, Left 4.80 CCI: Right 1.18, Left 1.12 (n = 46)		Differences not statistically significant (TES, p = 0.12; CCI, p = 0.17)
Accommodation (20 to 29 yr old)	*M* final: 9.1D *M* difference: 0.2D (n = 3)	*M* final: 7.5D *M* difference: -1.0D (n = 14)	Difference in *M* final statistically significant (**p = 0.04**); Difference in *M* difference not statistically significant (p = 0.22)
Accommodation (30 to 39 yr old)	*M* final: 6.2D *M* difference: -1.1D (n = 24)	*M* final: 6.7D *M* difference: -0.6D (n = 38)	Differences not significant: *M* final (p = 0.22); *M* difference (p = 0.25)
Accommodation (40 to 49 yr old)	*M* final: 4.4D *M* difference: -2.6D (n = 17)	*M* final: 4.4D *M* difference: -1.8D (n = 9)	Differences not significant: *M* final (p = 0.93); *M* difference (p = 0.31)
Accommodation (50 to 59 yr old)	*M* final: 3.4D *M* difference: -0.8D (n = 2)	*M* final: 3.2D *M* difference: 0.3D (n = 6)	Differences not significant: *M* final (p = 0.85); *M* difference (p = 0.11)
Accommodation	Within-subject differences Right: -1.85D Left: -1.80D		Difference not statistically significant (p = 0.76)
Eye muscle balance (Far)	2% (1) orthophoria; 85% (39) esophoria; 7% (3) exophoria; 61% (28) hyperphoria (n = 46)	3% (2) orthophoria; 86% (57) esophoria; 8% (5) exophoria; 62% (41) hyperphoria (n = 66)	Difference in distributions not statistically significant (p = 0.99)
Eye muscle balance (Near)	2% (1) orthophoria; 85% (39) esophoria; 11% (5) exophoria; 63% (29) hyperphoria (n = 46)	4.5% (3) orthophoria; 76% (50) esophoria; 16% (11) exophoria; 73% (48) hyperphoria (n = 66)	Difference in distributions not statistically significant (p = 0.54)
Eye dominance (Preference)	74% (34) right; 15% (7) left; 11% (5) neither (n = 46)	69% (48) right; 17% (12) left; 14% (10) neither (n = 70)	Difference in distributions not statistically significant (p = 0.81)
	Within-subject One subject measured as switching dominant eye; but, consistently reported the right eye as the preferred		

Note: Bold p-value implies a statistically significant difference.

Sighting eye preference

Of 65 control subjects responding, 75% (49) reported their right eye and 23% (15) reported their left eye as their preferred sighting eye; 1 control subject (1.5%) reported no preference. Sixty-nine control subjects provided responses for the specific viewing tasks of sighting with a telescope and viewing through a keyhole. Of subjects responding, 86% (59) indicated right eye preference for both viewing tasks; 13% (9) indicated left eye preference. One control subject (1.4%) reported no preference. Sixty-one (87%) responding control subjects were consistent across responses to the three sighting eye preference questions. Of these, 53 (87%) were right dominant in eye preference.

Forty-four exposed subjects completed all three questions regarding eye preferences. Of these, 84% (37) reported their right eye as their preferred sighting eye; 12% (5) reported their left eye and 4% (2) were undecided. For the specific viewing tasks of sighting with a telescope and viewing through a keyhole, 96% (42) and 93% (41) indicated right eye viewing preference, respectively. Left eye preference for these tasks was 5% (2) and 7% (3), respectively. Forty (91%) of responding exposed subjects were consistent across responses to the three sighting eye preference questions. Of these, 38 (95%) were right dominant in eye preference.

A Chi-square analysis found no significant difference between sighting eye preference distributions for the exposed and control subjects ($p = 0.22$).

Visual problems

Flight-related visual symptoms

When control subjects were asked to report on the presence of visual/physiological problems *during* flight, disorientation (60% of responding subjects) and headache (58%) were the most frequently cited symptoms; *after* flight, headache was the most frequently reported symptom (49%).

Exposed subjects reported headache (56% of responding subjects) and visual discomfort (51%), as the most frequently cited symptoms *during* flight and headache (51%) as the most frequent *after* flight. For all reported symptoms, the response was “Sometimes;”[18] no subject reported an “Always” response.

Headache was the most commonly reported symptom by both exposed and control subjects. For control subjects, headache was reported by approximately half of all subjects both *during* and *after* flight; disorientation (60%) was the most frequently reported symptom *during* flight for control subjects but was considerably less (36%) for exposed subjects. For exposed subjects, headache was the most frequently reported symptom both *during* and *after* flight, with visual discomfort ranked second for both *during* and *after* flight.

[18] If a subject reported a symptom as “Sometimes” on any annual questionnaire, it was used as such in the analysis.

A Chi-square analysis was conducted to evaluate whether exposed subjects reported a different headache frequency than control subjects, either *during* or *after* flight. No statistically significant differences were found for either *during* ($\chi^2 = 0.51$; $p = 0.61$) or *after* ($\chi^2 = 0.00$; $p = 1.00$) flight. However, similar tests found the greater frequency of disorientation symptoms for control subjects *during* flight ($\chi^2 = 5.67$; $p = 0.03$) and the greater frequency of visual discomfort symptoms for exposed subjects *during* flight ($\chi^2 = 8.68$; $p = 0.01$) to be significant. The difference in frequencies of visual discomfort *after* flight ($\chi^2 = 1.85$; $p = 0.27$) was not found to be significant.

Eye fatigue

Of the 60 responding control subjects, 45 (75%) reported eye fatigue, to some extent, during *night* flight as a result of using NVGs; 31 (86%) responding exposed subjects reported eye fatigue, to some extent, during *night* flight as a result of using the PNVS/IHADSS system (figure ES-1). A two-way contingency table analysis was conducted to test whether exposed subjects (86%) presented a different proportion of eye fatigue (to some extent) than control subjects (75%) during *night* flight. No significant difference was found ($\chi^2 = 1.08$, $p = 0.30$).

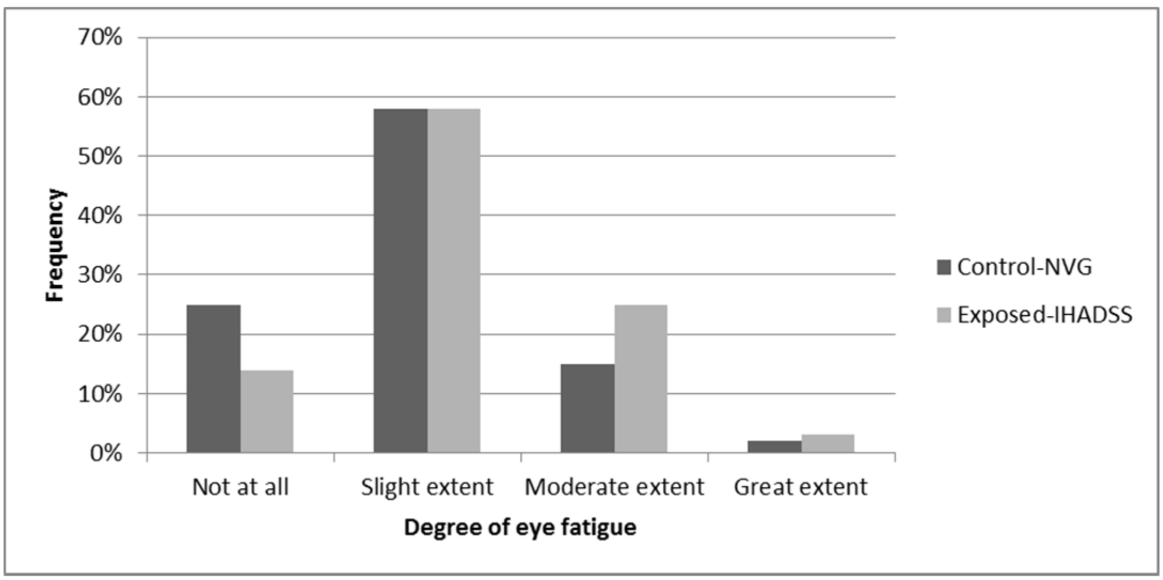

Figure ES-1. Comparison of eye fatigue, NVG vs. IHADSS (night flight).

Color adaptation

Of the 59 responding control subjects, 40 (68%) reported experiencing color perception problems after flying with NVGs. Subjects reported a persistent "browned vision" for up to 15 minutes post-flight. For exposed subjects, 19 (50%) responding subjects reported this phenomenon for flight with the IHADSS, again with most subjects reporting the effects disappearing in less than 15 minutes post-flight.

A two-way contingency table analysis found no significant difference in color adaptation (χ^2 = 2.37, p = 0.09). This finding was expected since both NVG and IHADSS stimuli are provided by the same monochromatic phosphor (P-43).

Spatial disorientation

Episodes of spatial disorientation, defined as a failure to perceive correctly one's position, motion, or attitude with respect to the Earth's surface or the acceleration due to gravity, were reported by 32% (12) of the exposed group and by 29% (17) of the control group, a difference that is not statistically significant (p = 0.66).

Handedness

Subject handedness (sometimes referred to as laterality) was assessed using a 10-item self-assessment questionnaire (appendix G) adapted from the Edinburgh Handedness Inventory (EHI) by Oldfield (1971). Both absolute and relative scores were computed for each subject.

The *absolute* handedness scores were predominantly "right" with 86% (56) of 65 responding control subjects indicating a preference for right-handedness and 14% (9) indicating left-handedness. The EHI *relative* scores largely confirmed this finding with an almost equal distribution: 88% (57) indicating right-handedness and 12% (8) indicating left-handedness. The mean EHI relative handedness score was +60 (right-handedness).

Exposed subjects' *absolute* handedness scores were predominantly "right" with 81% (35) of the 43 responding subjects, indicating a preference for right-handedness; 19% (8) of exposed subjects indicated left-handedness. The EHI *relative* scores confirmed this finding with the same distribution: 81% indicating right-handedness and 19% indicating left-handedness. The *M* EHI *relative* handedness score was +50 (right-handedness).

Both exposed and control subject groups indicated a predominant preference for right-handedness. A two-tailed Chi-square test showed no significant difference between the proportions of exposed subjects (R - 81%; L - 19%) and control subjects (R - 86%; L - 14%) (p = 0.58). The difference between the mean relative EHI scores of the two groups (Exposed - 50; Control - 60) was not statistically significant (p = 0.40).

Eye examination

Over the course of the 10-year study, a total 351 eye exams were conducted: 152 for exposed and 199 for control subjects. Table ES-4 provides a summary of the number of eye exams conducted in each year of the study (2001 to 2010).

The eye examination data show no statistically significant differences between exposed and control groups for any of the visual tests: mean refractive error, high and low contrast visual acuity, small letter contrast, depth perception, color perception, accommodative power, near and far eye muscle balance, and eye dominance.

Table ES-4.
Number of eye exams conducted by physical year of study (2001 to 2010).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Exposed	11	23	33	21	25	7	16	4	7	5	152
Control	31	37	42	28	13	4	27	8	5	4	199
Total	42	60	75	49	38	11	43	12	12	9	**351**

Refractive error

A standard method for summarizing refractive error is *spherical equivalent power*.[19] The final exam *M* spherical equivalent power (refractive error) for controls was essentially zero (-0.03D OD; 0.06D OS), clinically equivalent to emmetropia, while the exposed group had a *M* spherical equivalent power just slightly in the myopia range (-0.14D OD; -0.11D OS). Box plots of the final exam spherical equivalent power for the right and left eyes for both control and exposed subjects are presented in figure ES-2. These differences were not statistically significant (right eyes, p = 0.37; left eyes, p = 0.26). The numerical differences are to the order of 0.1 diopter (D), a value considered by vision specialists as functionally insignificant.

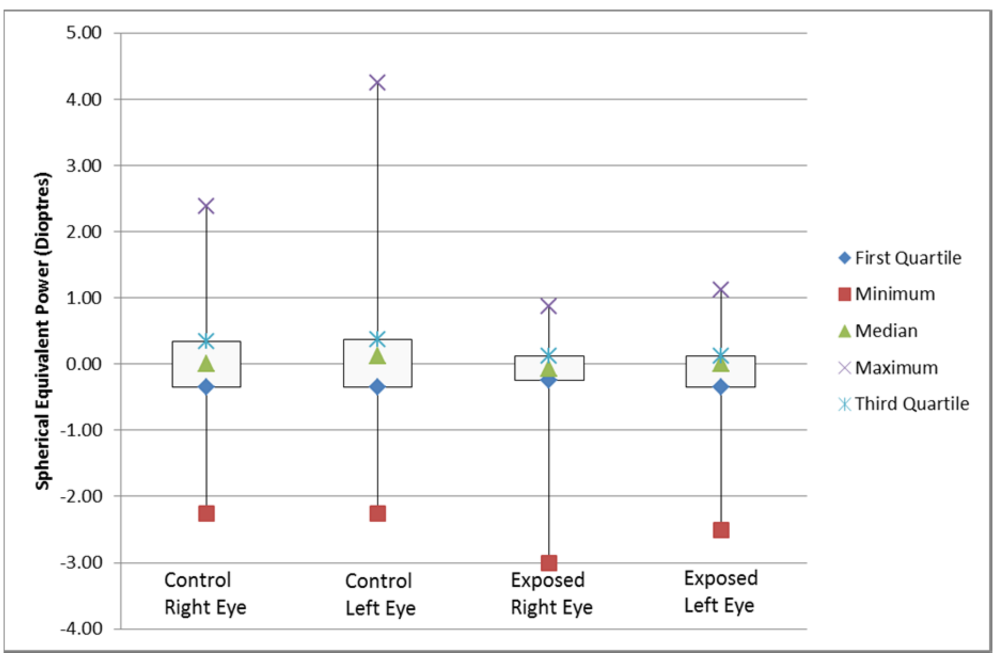

Figure ES-2. Box plot of spherical equivalent power for the right (OD) and left (OS) eyes for exposed and control subjects.[20]

[19] *Spherical equivalent power* is determined by combining the spherical power with half of the cylindrical power.
[20] The box-length is equivalent to the interquartile range of the data set.

A paired-samples *t*-test[21] was conducted to evaluate whether there was a significant difference in spherical equivalent refractive error scores between the final measurements for the right and left eyes for exposed subjects ($n = 46$). The results indicated that the *M* for the measurement for the right eye ($M = -0.14$, $SD = 0.61$) was not statistically significantly different from the *M* for the left eye ($M = -0.11$, $SD = 0.55$), with $p = 0.36$.

Bailey-Lovie high contrast visual acuity (HCVA)

For both groups, letters missed on the HCVA chart are converted to a logMAR (logarithm of minimum angle resolved) score for statistical/analytical purposes.

Bailey-Lovie HCVA values were available for 69 control subjects. For the right eye, the initial mean visual acuity was 0.10 logMAR (Snellen equivalent of 6/7.8 [20/26]); the final right eye mean visual acuity was 0.05 logMAR (Snellen equivalent of 6/6.9 [20/23]). For the left eye, the initial mean visual acuity was 0.11 logMAR (Snellen equivalent of 6/8.1 [20/27]); the final left eye mean visual acuity was 0.06 logMAR (Snellen equivalent of 6/7.2 [20/24]). The control subjects' mean absolute value individual differences between final and initial HCVA values were 0.10 and 0.11 logMAR for the right and left eyes, respectively.

For exposed subjects ($n = 43$), for the right eye, the initial mean Bailey-Lovie HCVA was 0.14 logMAR (Snellen equivalent of 6/8.7 [20/29]; the final right eye mean visual acuity was 0.07 logMAR (Snellen equivalent of 6/7.2 [20/24]. For the left eye, the initial mean visual acuity was 0.13 logMAR (Snellen equivalent of 6/8.1 [20/28]; the final left eye mean visual acuity was 0.08 logMAR (Snellen equivalent of 6/7.5 [20/25]). The exposed subjects' mean absolute value individual differences between final and initial HCVA values were 0.10 and 0.08 logMAR for the right and left eyes, respectively.

There was not a statistically significant difference in the final Bailey-Lovie HCVA for the two groups (right eyes, $p = 0.30$; left eyes, $p = 0.58$).

A paired-samples *t*-test was conducted to evaluate whether there was a significant difference in Bailey-Lovie HCVA scores between the final measurements for the right and left eyes for exposed subjects ($n = 43$). The results indicated that the *M* for the measurement for the right eye ($M = 0.07$ logMAR, $SD = 0.11$) was not statistically significantly different from the *M* for the left eye ($M = 0.08$ logMAR, $SD = 0.12$), with $p = 0.67$.

Bailey-Lovie low contrast visual acuity (LCVA)

For both groups, letters missed on the LCVA chart were converted to a logMAR score for statistical/analytical purposes. Bailey-Lovie LCVA values were available for 49 control subjects. For the right eye, the final right eye mean visual acuity was 0.26 logMAR (Snellen equivalent of 6/11.4 [20/38]). The final left eye mean visual acuity was 0.29 logMAR (Snellen

[21] The paired samples *t*-test is used to test the null hypothesis that the average of the differences between a series of paired observations (e.g., right vs. left eye) is zero.

equivalent of 6/12 [20/40]). The control subjects' mean absolute value individual differences between final and initial LCVA values were 0.15 and 0.12 logMAR for the right and left eyes, respectively.

For 43 exposed subjects, the final right eye mean visual acuity was 0.30 logMAR (Snellen equivalent of 6/12.6 [20/42]). For the left eye, the final mean visual acuity was 0.30 logMAR (Snellen equivalent of 6/12.6 [20/42]). The exposed subjects' mean absolute value individual differences between final and initial HCVA values were 0.12 and 0.13 logMAR for the right and left eyes, respectively.

The ability to see low contrast letters is affected by the optics of the eye, uncorrected refractive error, and/or the sensitivity of the retina. Optics of the eye include clarity of the media, specifically the cornea and lens, and pupil size; both tend to decrease with age. The mean age difference between the two groups was very small at 3 years, the two groups are still relatively young, and changes are generally not evident until the fifth or sixth decade of life. There was not a statistically significant difference in the LCVA for the two groups for either right or left eyes (right eyes, $p = 0.13$; left eyes, $p = 0.68$).

A paired-samples *t*-test was conducted to evaluate whether there was a significant difference in Bailey-Lovie LCVA scores between the final measurements for the right and left eyes for exposed subjects ($n = 43$). The results indicated that the *M* for the measurement for the right eye (*M* = 0.30 logMAR, *SD* = 0.12) was not statistically significantly different from the *M* for the left eye (*M* = 0.30 logMAR, *SD* = 0.13), with $p = 0.83$.

Small letter contrast sensitivity

For both groups, letters missed on the Small Letter Contrast Chart (SLCT) were converted to a logCS score for statistical/analytical purposes. SLCT data values were taken for 63 control subjects. For the right eye, the mean final contrast sensitivity was 1.05 logCS (*SD* = 0.21); the final left eye *M* was 1.07 logCS (*SD* = 0.16). For exposed subjects ($n = 43$), the final right eye mean contrast sensitivity was 1.02 logCS (*SD* = 0.24). For the left eye, the final *M* was 1.04 logCS (*SD* = 0.21). There was not a statistically significant difference between groups for final SLCT scores (right eyes, $p = 0.39$; left eyes, $p = 0.68$).

A paired-samples *t*-test was conducted to evaluate whether there was a significant difference in SLCT scores between the final measurements for the right and left eyes for exposed subjects ($n = 43$). The results indicated that the *M* for the measurement for the right eye (*M* = 01.02 logCS, *SD* = 0.24) was not statistically significantly different from the *M* for the left eye (*M* = 1.04 logCS, *SD* = 0.21), with $p = 0.67$.

Depth perception

Depth perception was measured in seconds of arc (arcsec). Initial control subject ($n = 70$) scores ranged from 20 to 50 arcsec with a *M* and *Mdn* of 26.4 (*SD* = 4.2) and 25.0 arcsec, respectively; final scores ranged from 20 to 70 arcsec with a *M* and *Mdn* of 28.4 (*SD* = 12.1) and 25 arcsec, respectively. The mean difference between initial and final scores for control subjects

was 2.0 arcsec. For exposed subjects ($n = 45$), initial scores ranged from 20 to 30 arcsec with a *M* and *Mdn* of 25.9 (*SD* = 2.7) and 25.0 arcsec, respectively; final scores ranged from 20 to 70 arcsec with a *M* and *Mdn* of 28.6 (*SD* = 12.2) and 25 arcsec, respectively. The mean difference between initial and final scores for exposed subjects was 2.7 arcsec. There was no statistically significant difference between the groups for final scores ($p = 0.93$) or for differences between final and initial scores ($p = 0.78$).

Color perception

The Lanthony desaturated D-15 hue test, adapted from the Farnsworth Panel D-15 test, was used. This test consists of 16 color chips/tabs selected from the Munsell (1929) book of color that are desaturated and appear pale and light. In order to compare small differences in performance, a modified Farnsworth-Munsell (1943) FM-100 test quantitative perception scoring scheme was used. This test was conducted monocularly for both left and right eyes. Scoring was performed using a web-based computer program designed for analyzing the Lanthony desaturated D-15 hue test and reporting a total error score (TES) (Torok, 2011). A second metric that was calculated from the D-15 test is the Color Confusion Index (CCI). The CCI is a measure the severity of the color deficit.

For 70 control subjects, the mean final TES and CCI scores for the right eye were 4.2 (*SD* = 6.28) and 1.1 (*SD* = 0.18), respectively. For the left eye, the mean final TES and CCI scores were 4.2 (*SD* = 7.16) and 1.1 (*SD* = 0.25), respectively. Differences in both TES and CCI scores were calculated based on initial and final scores. Mean TES and CCI differences for the right eye were -1.77 (*SD* = 7.12) and -0.05 (*SD* = 0.20), respectively. For the left eye, mean final TES and CCI differences were -0.56 (*SD* = 9.40) and -0.02 (*SD* = 0.26), respectively. For these difference statistics, a negative value implies an improvement (however small) in color perception.

For 46 exposed subjects, the mean final TES and CCI scores for the right eye were 6.83 (*SD* = 9.91) and 1.18 (*SD* = 0.36), respectively. For the left eye, the mean final TES and CCI scores were 4.80 (*SD* = 7.54) and 1.13 (*SD* = 0.30), respectively. Differences in both TES and CCI scores were calculated based on initial and final scores. Mean TES and CCI differences for the right eye were 0.67 (*SD* = 9.32) and 0.00 (*SD* = 0.32), respectively. For the left eye, mean final TES and CCI differences were -1.59 (*SD* = 7.07) and -0.07 (*SD* = 0.28), respectively.

The differences in TES and CCI scores for both groups were extremely small. There was not a statistically significant difference between the groups for either the TES differences (right eyes, $p = 0.13$; left eyes, $p = 0.50$) or CCI differences (right eyes, $p = 0.40$; left eyes, $p = 0.36$).

Paired-samples *t*-tests were conducted to evaluate whether there was a significant difference in TES and CCI scores between the final measurements for the right and left eyes for exposed subjects ($n = 46$). The results indicated that the means for both the TES and CCI measurements for the right eye (TES $M = 6.83$; CCI $M = 1.18$) were not statistically significantly different from the means for the left eye (TES $M = 4.80$; CCI $M = 1.13$), with $p = 0.12$ and $p = 0.177$, respectively.

Accommodation

In a standard aircrew medical examination, accommodation is measured in a binocular fashion, stimulating convergence and accommodation together by maintaining focus and fusion on a target. In this study, accommodation without spectacle correction was tested binocularly and monocularly by moving a small-print target on a Prince Rule slowly away from each eye in turn, noting when the subject can read the letters on the target.

Accommodation data were available for 67 control subjects. The results are presented based on *age at last* exam date (in decade groups).[22] The *M* and *Mdn* ages across all control subjects were 35.2 and 32 years, respectively. By decade, 14 subjects were 26 to 29 years of age (*Mdn* = 27 years); 38 subjects were 30 to 39 years of age (*Mdn* = 35 years); 9 subjects were 40 to 47 years of age (*Mdn* = 42 years); and 6 subjects were 50 to 55 (*Mdn* = 51.5 years).

Accommodation data were available for 46 exposed subjects. The *M* and *Mdn* ages across all exposed subjects were 38.1 and 38 years, respectively. By decade, 3 subjects were 28 to 29 years of age (*Mdn* = 28 years); 24 subjects were 30 to 39 years of age (*Mdn* = 35 years); 17 subjects were 40 to 48 years of age (*Mdn* = 42 years); and 2 subjects were 52 to 54 (*Mdn* = 53 years).

Three approaches using binocular data were used to investigate potential between-subject differences in accommodation. In the first approach, final accommodation values were compared. The second approach compared differences between final and initial accommodation values. The final approach compared rates of accommodative change, expressed in diopters (D) per year of study participation. Lastly, difference and rate of change accommodation values are summarized by decade in table ES-5.

Table ES-5.
Summary of binocular accommodation values (in diopters).

Decade range	Control (*n* = 67)	Exposed (*n* = 46)	Comparison
20 to 29 years	***n* = 14**	***n* = 3**	
M final	7.5D	9.1D	***p* = 0.04**
M difference	-1.0D	0.2D	*p* = 0.22
M rate of change (D/Year)	0.1	0.0	*p* = 0.79
30 to 39 years	***n* = 38**	***n* = 24**	
M final	6.7D	6.2D	*p* = 0.22
M difference	-0.6D	-1.1D	*p* = 0.25
M rate of change (D/year)	-0.2	-0.4	*p* = 0.27
40 to 49 years	***n* = 9**	***n* = 17**	
M final	4.4D	4.4D	*p* = 0.93
M difference	-1.8D	-2.6D	*p* = 0.31
M rate of change (D/year)	-0.3	-0.7	*p* = 0.17
50 to 59 years	***n* = 6**	***n* = 2**	

[22] The amplitude of accommodation declines with age. By the fifth decade of life, the accommodative amplitude has declined so the near point of the eye is more remote than the reading distance (Borish, 1954).

M final	3.2D	3.4D	$p = 0.85$
M difference	0.3D	-0.8D	$p = 0.11$
M rate of change (D/year)	0.1	-0.1	$\mathbf{p = 0.01}$

Note: **Bold *p*-values** imply a statistically significant difference.

Compared using 2-tailed *t*-tests, only the 20 to 29 year decade final values and the 50 to 59 year decade mean rate of change were found to be significantly different ($p = 0.04$ and $p = 0.01$, respectively); however, the number of subjects present in these comparisons were very small.

The mean exposure time between all exposed subjects' first and last measurements was 4.0 years, and the mean age of the exposed subjects at the final measurement was 38.1 years. The mean change in accommodative power across both eyes was approximately -1.8D. It is well known that the amplitude of accommodation declines with age to less than 2D by the time a person reaches 45 to 50 years of age. An additional analysis was conducted using the changes in accommodative power for the right and left eyes. A paired *t*-test was performed on the differences between first and final values for the right ($M = -1.85$D) and left ($M = -1.80$) eyes was not found to be significant ($p = 0.76$).

Eye muscle balance

Eye muscle balance was measured with the Optec® 2000 Vision Tester for both *far* (i.e., 6 meters [m]; 20 feet [ft]) and *near* (~½ m; 18 inches [in]) distance conditions. Two of the 66 control subjects were measured as having orthophoria at *far* distance; three were orthophoric at *near* distance. All other control subjects had a measurable heterophoria at *far* and *near* distances. For *far* distance, 57 (86%) were esophoric, 5 (8%) were exophoric, and 41 (62%) were hyperphoric. Esophoria ranged from 1 to 8 prism diopters; exophoria ranged from 1 to 3 prism diopters; and hyperphoria ranged from was 0.5 to 1 prism diopters, right and left. For *near* distance, 50 (76%) control subjects were esophoric, 11 (16%) were exophoric and 48 (73%) were hyperphoric. Esophoria ranged from 1 to 12 prism diopters; exophoria ranged from 1 to 2 prism diopters; and hyperphoria ranged from 0.5 to 1.5 prism diopters, right and left.

Of 46 exposed subjects, 1 subject each was measured to have orthophoria at *far* or *near* distance. All other subjects had a measurable heterophoria at *far* distance; 39 (85%) were esophoric, 3 (7%) were exophoric, and 28 (61%) were hyperphoric (22 right and 6 left). Esophoria ranged from 1 to 9 prism diopters ($M = 2.6$ prism diopters); exophoria ranged from 1 to 3 prism diopters ($M = 2.3$ prism diopters); and hyperphoria ranged from was 0.5 to 1 prism diopters right and 0.5 to 1.5 prism diopters left. All 46 exposed subjects had a measurable heterophoria at *near* distance; 39 (85%) were esophoric, 5 (11%) were exophoric, and 29 (63%) were hyperphoric (4 right and 25 left). Esophoria ranged from 1 to 11 prism diopters ($M = 5.0$ prism diopters); exophoria ranged from 1 to 2 prism diopters ($M = 1.6$ prism diopters); and hyperphoria ranged from was 0.5 to 1 prism diopters right and 0.5 to 2 prism diopters left.

The far and near distributions of heterophorias were very similar for both groups and was not statistically different between groups (*far*, $p = 0.99$; *near*, $p = 0.54$).[23]

Eye dominance

Using the Dolman method "hole" test (Cheng et al., 2004), eye dominance was measured for all exposed and control subjects. Sixty-nine percent (48) of the 70 control subjects were measured to have "right" eye dominance; 17% (12) were measured to have "left" eye dominance; and 14% (10) failed to show dominance in neither eye.[24] Seventy-four percent (34) of the 46 exposed subjects were measured to have "right" eye dominance; 15% (7) were measured to have "left" eye dominance; and 11% (5) failed to show dominance in neither eye. The distribution of results for the eye dominance test for control and exposed subjects is presented in figure ES-3.

Both groups demonstrated similar distributions for the "hole" dominance test, with larger proportions for right eye dominance. A Chi-square analysis found no significant difference between these proportion distributions ($p = 0.81$).

Of the 46 exposed subjects for whom eye preference (dominance) data were available for at least two exams, 38 subjects (83%) were measured as having the same (consistent) eye preference. An additional seven subjects (15%) were inconsistent in measured preference, in most cases alternating between right and left. Only one subject (2%) was found to have switched dominant eye, having been measured as having right eye preference for three exams and then left eye preference for the next three exams. However, this same subject overwhelmingly reported his right eye as his preferred eye for sighting and for the monocular tasks viewing through a telescope and through a keyhole (Questions 17 to 19 in the annual questionnaires).

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[23] Chi-square tests and Freeman-Halton extension of Fisher exact probability tests for the eye muscle 2 x 4 contingency tables failed to meet the necessary expected cell frequency and total frequency (*N*) values criteria; therefore, reported *p*-values are based on 2 x 3 contingency tables excluding orthophoria frequencies.

[24] For the majority of both control and exposed subjects, eye dominance measurements were in agreement for all tests. However, if a subject's dominance measurement was inconsistent, specific *right* or *left* eye dominance was designated when the ratio of one dominance type to the other equaled or exceeded 2:1. If this ratio criteria was not met, the subject was designated as having *neither* eye dominant, i.e., undecided.

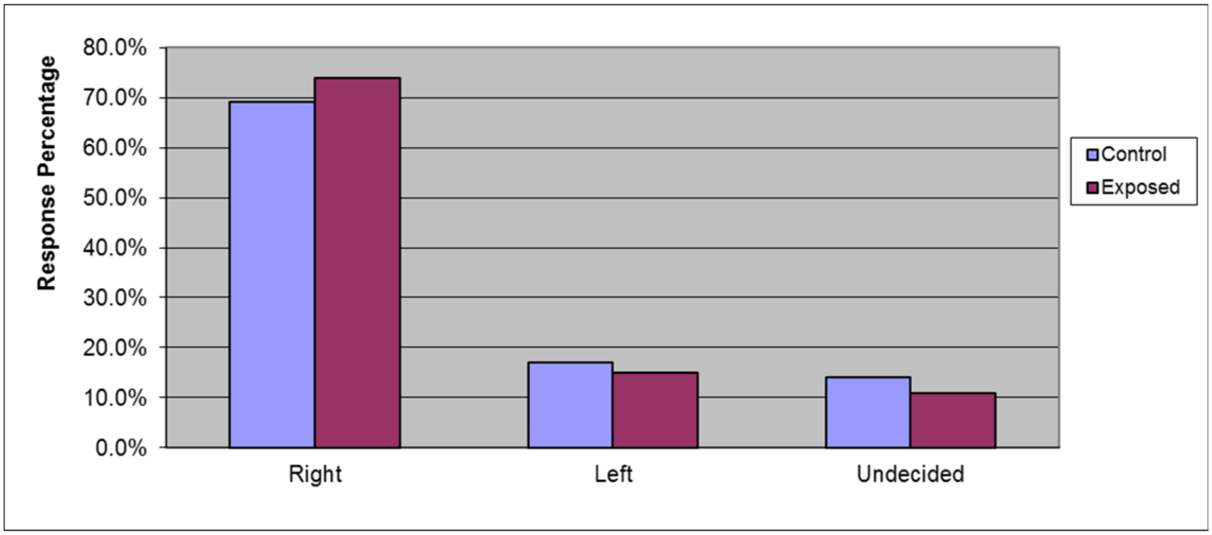

Figure ES-3. Eye dominance distribution for control (*n* = 70) and exposed (*n* = 46) subjects.

Conclusions

There is no evidence that the prolonged use of the monocular IHADSS HMD has produced any operationally meaningful differential vision changes between the two eyes or that the visual performance of exposed subjects differed from the performance of control subjects.

However, for the test parameters of accommodation and eye dominance, two minor differences warrant mention and explanation. For binocular accommodation examined by decade of age (based on age at last exam), a significant finding (p = 0.04) was present for the 20 to 29 year decade group. Fourteen control subjects (26 to 29 years of age) had a *M* accommodation of 7.5D; three exposed subjects (28 to 29 years of age) had a *M* accommodation of 9.1D. An examination of individual data values failed to show any outliers or other possible explanations. For the purpose of this study, the 1.6D of difference is being interpreted as a statistical anomaly associated with the small sample of three subjects in the exposed group.

Lastly, one exposed subject was measured as having switched dominant eye from left to right during participation in the study, based on the Dolman method "hole test" for eye dominance (Cheng et al., 2004). This subject was measured as right-eye dominant for the first three years of participation and as left-eye dominant for a subsequent three years of participation. Interestingly, this subject self-reported his right eye as his preferred eye in all annual questionnaires. While striking in the pattern of change for this subject, 20% of control subjects and 17% of exposed subjects were measured as having inconsistent dominant eye determinations during their participation in the study.

Eye dominance is difficult to objectively measure, and results of ocular dominance tests seem to vary depending on both the testing distance and the specific activity performed as part of the testing procedure (Rice et al., 2008). The optimum method for evaluating ocular dominance

remains a topic of controversy among vision scientists. Therefore, the reversal of measured eye dominance by the "hole test" for this subject is not considered of consequence.

Recommendations

In hindsight, the 10-year period of the study was too lengthy for studying a military aviation cohort. The hope of retaining pilots for that long of a period was overly ambitious. The original study design anticipated a minimum of 80 exposed and 300 control subjects by the midpoint (end of 5th year) of the study. This goal was not achieved. Across the full study, exposed subjects participated in the study for a mean period of approximately 3.6 years (43 months). Control subjects had a comparable mean period of participation of 3.8 years (45 months). Factors that influenced subject recruitment and retention included delays in the initial fielding of the AH Mk one Apache aircraft, the inclusions of junior officers (who have short flying careers), retirements, geographically dispersed subject populations, and unanticipated and prolonged military actions in Iraq and Afghanistan. While the occurrences of military actions could not be expected to be anticipated, their impact and the impact of the other factors could have been mitigated by a shorter study period. Although longitudinal studies, by their design, involve repeated observations of the same subjects that are conducted over a long period of time, thereby making observing changes more accurate, the nature of the military aviation community introduces many obstacles to long-term study. Therefore, it is recommended that future studies of this type consider shorter periods of observation that can accommodate the challenges of this community.

After the various issues impacting subject retention, the next factor having the greatest impact on the study was the inability to achieve a high subject compliance with completion and submission of the annual questionnaire. The questionnaire was overly ambitious and consisted of 82 multi-part questions addressing flight experience, vision history, disorientation, neck and back pain, helmet usage, contact lens use, and handedness. To minimize its impact on subject time resources, the distribution and collection of the questionnaires were handled independently from the annual expanded vision exam. As a result, many subjects failed to consistently provide questionnaires to match the annual vision exams. Consequently, important correlated data were failed to be collected. The most important of these data were those of flight experience. This resulted in an underreporting of flight hours. While it was important to subject recruitment and retention that the time requirements of the study on subject schedules be minimized, subjects who reported for their vision exam without having submitted their corresponding questionnaire should have been asked to complete one at that time.

<u>Preface</u>

This is the final report for the study titled *The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots*. The principal aim of this occupational health study was to determine if the use of the monocular IHADSS HMD in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual (specifically binocular) performance. Additional information concerning other unique problems of the Apache AH Mk 1 aircrew was elicited as a secondary objective (e.g., helmet usage, neck and back pain, and handedness).[25] This study was a collaborative effort between the British Army and the U.S. Army and was conducted under the auspices of TTCP, Subgroup HUM, Technical Panel 7 (Human Factors in the Aviation Environment). The actively participating organizations were the Headquarters Director Army Aviation (HQ DAAvn),[26] Middle Wallop, United Kingdom and the U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, United States.

A cohort of British Apache AH Mk 1 pilots (exposed group) and a control group of British Army pilots who fly helicopter models other than the Apache were followed over a 10-year period. Data were collected via annual eye exams and questionnaires.

The study protocol received ethical clearance through the Defence Medical Services Ethics Committee (United Kingdom) in January 2000. The Headquarters Director of Army Aviation (DAAvn) (United Kingdom) and the Headquarters of the Joint Helicopter Command (United Kingdom) both approved the study in 2000. The protocol also was approved by the USAARL Scientific and Human Use committees over the period of December 1999 to January 2000.

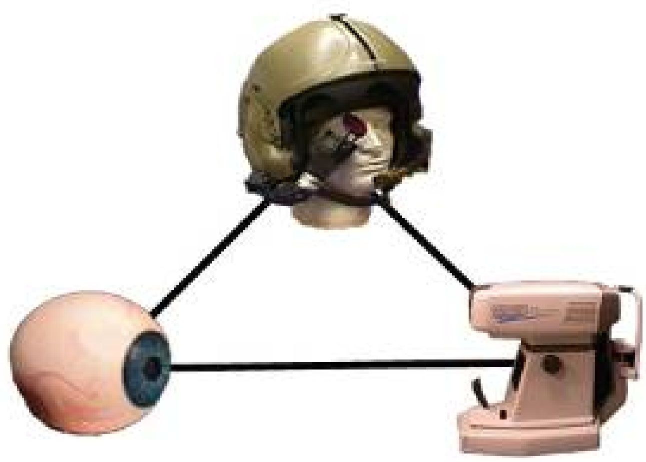

Figure ES- 4. The Apache AH Mk 1 cohort study logo.

An initial report describing the study's protocol, methodology, development and initial execution phase was published in November 2001 as USAARL Report No. 2002-04 (Hiatt et al.,

[25] Data for non-visual performance parameters, e.g., helmet use, head and neck pain, and handedness, are reported separately (Walters et al., 2013).
[26] HQ DAAvn is currently the Headquarters Army Air Corps (HQ AAC).

2002a). The first interim (two-year) report was published in September 2004 as USAARL Report No. 2004-18 (Rash et al., 2004); a second interim (4-year) report for the period of January 2000 to December 2004 was published in December 2009 as USAARL Report 2010-09 (Rash et al., 2010) and presented at the Aerospace Medical Association in May 2008 (Adams et al., 2008); a 6-year study review was presented at the 2009 SPIE Head- and Helmet-Mounted Displays XIV Conference, Orlando, FL, and published in the conference proceedings (SPIE, Proceedings Vol. 7326 [Hiatt et al., 2009]). Due to loss of key U.S. personnel, an 8-year interim report was not published; however, a data review was performed by the U.S. Aeromedical exchange flight surgeon to fulfill duty-of-care obligations to ensure subject health and safety.

Acknowledgments

This work is supported by the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, AL; the Ministry of Defence – British Army Air Corps (AAC), United Kingdom; and the Drummond Trust Foundation, administered by the Military Assistant to The Director General Army Medical Services. Army Medical Directorate, Keogh Barracks, Aldershot, Hampshire, United Kingdom.

The ambitious scope of this study has necessitated a large effort by a great number of individuals over an extended time period. The role and contributions of the major contributors are as follows (in alphabetical order) and reflect the title(s) and assignments of the individuals at the time they became a contributor to the study:

- Lt Col Mark S. Adams, RAMC, Consultant Adviser in Aviation Medicine, Headquarters Director Army Aviation (HQ DAAvn), Middle Wallop, United Kingdom, served as British study leader (2005-09) and as Flight Surgeon (British Exchange Officer), Warfighter Protection Division, USAARL, Fort Rucker, AL, United States, served as study principal co-investigator (2012 to 2013).

- COL Malcolm G. Braithwaite, OBE, L/RAMC, Consultant Adviser (CA) in Aviation Medicine, Headquarters Director Army Aviation, Middle Wallop, United Kingdom, co-authored the original study protocol and served as British study leader (1998 to 2005).

- LTC Jose Capo-Aponte, OD, Branch Chief, Visual Sciences Branch, Aircrew Health and Performance Division, USAARL, Fort Rucker, AL, United States, served as U.S. vision consultant to study (2009 to 2013).

- MAJ Jeffery M. Cleland, OD, Branch Chief, Visual Sciences Branch, Aircrew Health and Performance Division, USAARL, Fort Rucker, AL, United States, served as U.S. vision consultant to study (2005 to 2006).

- COL (Retired) John S. Crowley, MD, MPH, U.S. Army Medical Corps, Director, Aircrew Protection Division, USAARL, Fort Rucker, AL, United States, co-authored the original study protocol (1998 to 1999).

- Lt Col Allison J. Eke, RAMC, Consultant in Aviation Medicine, formerly at Defence Evaluation and Research Agency, Centre for Human Sciences, Farnborough, United Kingdom, participated in development of study protocol (1998 to 1999).

- LTC Steven J. Gaydos, MD, MPH, U.S. Army Medical Corps, Aviation Medicine Exchange Officer, Headquarters Army Air Corps (HQ AAC), Middle Wallop, United Kingdom, serves as the Aeromedical Exchange Officer to United Kingdom (2011 to 2013).

- Lt Col Michael J. Harrigan, Consultant Adviser in Aviation Medicine, HQ AAC, Middle Wallop, United Kingdom, serves as British study leader (2009 to 2013).

- Eric S. Harris, student researcher, Aircrew Health and Performance Division, USAARL, Fort Rucker, AL, United States, performed data entry and extensive analysis for 2-year and 4-year reports (2004 to 2005).

- COL Keith L. Hiatt, MD, MPH, U.S. Army Medical Corps, Aviation Medicine Exchange Officer, HQ DAAvn, Middle Wallop, United Kingdom, served as the Aeromedical Exchange Officer to the United Kingdom and study's initial principal investigator for period of 2000 to 2002; co-authored all study reports; serves as study medical consultant (2000 to 2013).

- Melissa L. Isaak, BS, MS, student researcher, Aircrew Health and Performance Division, USAARL, Fort Rucker, AL, United States, performed data entry and data analysis for the two-year report (2000 to 2002).

- COL (Retired) Ronald P. King, MD, MPH, U.S. Army Medical Corps, Aviation Medicine Exchange Officer, HQ DAAvn, Middle Wallop, United Kingdom, was the Aeromedical Exchange Officer to United Kingdom and served as the study's British principal investigator for the period 2002 to 2005.

- LTC Gregory T. Lang, MD, MPH, U.S. Army Medical Corps, Aviation Medicine Exchange Officer, HQ DAAvn, Middle Wallop, United Kingdom, was the Aeromedical Exchange Officer to the United Kingdom and served as the study's British principal investigator for the period 2009 to 2011.

- SPC Lisa J. Lewis, BS, Research Technician, Aircrew Health and Performance Division, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL, United States, performed database entry and analysis for two-year report (2000 to 2002).

- LTC (Retired) Corina van de Pol, OD, PhD, USAARL, Fort Rucker, AL, United States, served as vision consultant to study (2000 to 2005).

- Daniel J. Ranchino, BS, computer specialist, Research Support Division, USAARL, Fort Rucker, AL, United States, developed architecture for study database (2002).

- Clarence E. Rash, BS, MS, research physicist, Sensory Research Division, USAARL, Fort Rucker, AL, United States, developed visual test battery; served as U.S. technical coordinator (2000 - 2010, 2012 to Present); co-authored all study reports.

- COL William K. Statz, DO, MPH, U.S. Army Medical Corps, Formerly at Defence Evaluation and Research Agency Centre for Human Sciences, Farnborough, United Kingdom, participated in development of study protocol as former Aeromedical Exchange Officer to the United Kingdom (1998 to 1999).

- MAJ David V. Walsh, OD, Visual Sciences Branch Chief, Sensory Research Division, USAARL, Fort Rucker, AL, United States, served as U.S. vision consultant to study (2012 to Present).

- Lt Col P. Lynn Walters, Specialist in Aviation Medicine, HQ DAAvn, Middle Wallop, United Kingdom (2000 to 2001, 2004 to 2005); Specialist in Aviation Medicine, Dishforth Airfield, Boroughbridge, North Yorkshire, United Kingdom (2005 to 2006, 2007 to 2009); Flight Surgeon (British Exchange Officer), Warfighter Protection Division, USAARL, Fort Rucker, AL, United States, served as study principal co-investigator (2011 to 2012).

- COL Raymond W. Watters, MD, MPH, U.S. Army Medical Corps, Aviation Medicine Exchange Officer, HQ DAAvn, Middle Wallop, United Kingdom, was the Aeromedical Exchange Officer to the United Kingdom and served as the study's principal investigator in the United Kingdom (2006 to 2007).

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Introduction

In the 1970s, the U.S. Army initiated a program to build an advanced attack helicopter (designated as the AH-64 Apache)[1] to replace its aging fleet of AH-1 Cobra helicopters, which had been in service since the early 1960s. The AH-64 Apache is a twin-engine, four bladed, attack helicopter designed to operate during the day, night, and in adverse weather through the use of nose-mounted, forward-looking infrared (FLIR) pilotage and targeting sensors that provide a thermal image of the outside world to the pilot. This imagery is presented to the pilot via a head-up, helmet-mounted display (HMD).

Due to engineering technology limitations of the era, the HMD was constructed to present pilotage imagery only to one eye, the right eye. This monocular design was driven by the paramount need to minimize head supported weight and any shift in center-of-mass (CM). This monocular presentation to the human visual system, which itself is binocular in nature, raised concerns among vision scientists involved in the early design, e.g., binocular rivalry[2] and the Pulfrich phenomenon.[3] While these particular concerns never manifested themselves to the levels initially feared, they and a host of visual complaints and illusions attributed to the monocular HMD have plagued AH-64 pilots ever since the fielding of this aircraft by the U.S. Army in the early 1980s.

The British government initially fielded the Westland Apache AH Mk 1 attack helicopter (formerly identified as the WAH-64) in 2000 to 2001. The Apache AH Mk 1 (figure 1) is an improved version of the AH-64D "Apache Longbow" helicopter flown extensively by the U.S. Army. Improvements included fire-control radar, improved weapons processors, a "glass" cockpit (integral to the D-model), improved data modem, and a multitude of engineering enhancements to components and overall system architecture. This acquisition program was considered an "off-the-shelf" buy, and, in many respects, the British Apache AH Mk 1 is similar to the U.S. Army's Apache Longbow AH-64D helicopter.

The protective flight helmet used to date by AH-64 pilots is the Integrated Helmet and Display Sighting System (IHADSS) (figure 2) (Rash and Martin, 1988). The IHADSS provides sensor video and/or symbology to each crewmember via a helmet display unit (HDU). The HDU contains a 1-inch (in.) diameter cathode ray tube (CRT) attached to the right side of the helmet, positioning a combiner lens directly in front of the pilot's right eye. When in use, the HDU usually rests on the pilot's right maxilla/zygomatic arch (right cheekbone); when not needed, it can be rotated away from the face.

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[1] The original (alpha) model of the AH-64 (Manufactured by Boeing Aircraft) was designated as the AH-64A; an improved version, designated as the AH-64D (Longbow Apache), was fielded in 1998 and incorporated a millimeter wave fire-control radar, radar frequency interferometer, fire-and-forget radar-guided HELLFIRE missile, and cockpit management and digitization enhancements (including a "glass" cockpit).
[2] The switching (or suppression of a discerned image over time) between images produced by the two eyes viewing different images.
[3] A binocular visual effect in which a lateral motion in a plane parallel to the face appears to move in an elliptical path.

The sensor video imagery presented by the IHADSS can originate from either of two thermal (FLIR) sensors mounted on the nose of the aircraft. Pilotage imagery is provided by the Pilot's Night Vision System (PNVS); targeting imagery is provided by the Target Acquisition and Designation System (TADS).

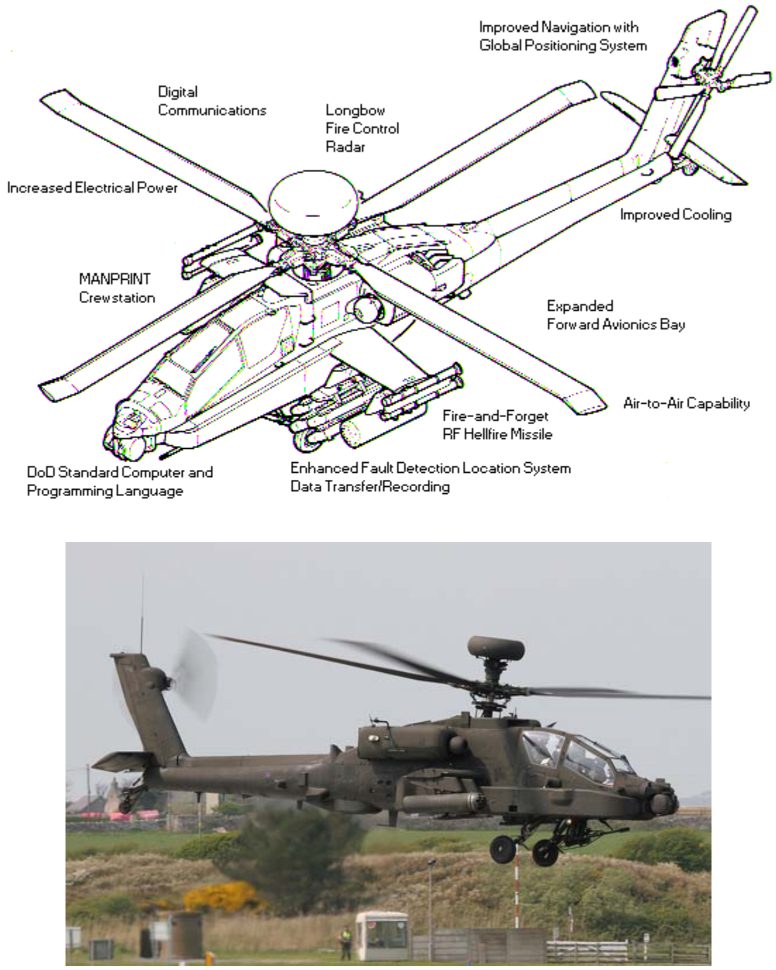

Figure 1. The Westland Apache AH Mk 1 (bottom), similar to the Boeing Longbow AH-64D (top) (Sale and Lund, 1993).

For flight in night-time and degraded visual conditions, the Apache pilot's primary source of visual information about the aircraft's state and the outside environment is the HDU. Compelling the pilot to rely on a degraded, unnatural view of the world, which is provided only to the right eye, has been noted to cause psychological and physiological problems for many Apache pilots (Behar et al., 1990; Rash and Martin, 1988).

Shortly after the initial fielding of the AH-64A by the U.S. Army in 1980, numerous anecdotal reports of various physical, psychological and sensory-related problems surfaced. User surveys documented increased rates of fatigue and other symptoms generally attributed to the IHADSS/ HDU (Behar et al., 1990; Crowley, 1991). Hale and Piccione (1990) conducted the first user

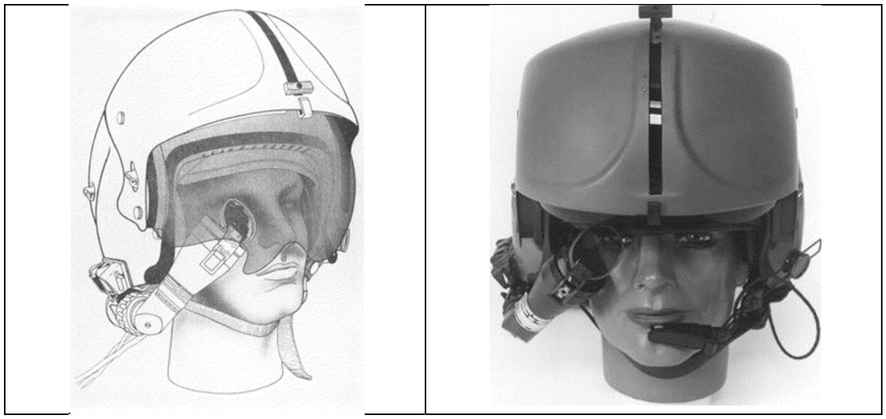

Figure 2. The AH-64 Integrated Helmet and Display Sighting System (IHADSS) with the HDU mounted in front of the pilot's right eye (Rash and Martin, 1988).

survey of 52 instructor pilots at Fort Rucker, AL, and found evidence of increased aviator fatigue and, among other complaints, headaches. They cited as possible causes the following IHADSS-related factors: binocular rivalry, narrow field-of-view (FOV), poor depth perception, inadequate eye relief, and overall system discomfort. In 1990, Behar et al. (1990) surveyed 58 Apache aviators and found that more than 80% of the sample reported at least one visual complaint associated with flying or after flying with the IHADSS. The most common complaint (51%) was that of "visual discomfort" *during* flight. Approximately one third of the aviators reported occasional headaches, and approximately 20% reported blurred vision and/or disorientation *while* flying. The percentage of aviators reporting headache and blurred vision *after* flying remained about the same, while the percentage of those experiencing disorientation *after* flying decreased to 5%. In 2000, ten years later, Rash et al. (2001) conducted a web-based survey basically replicating the 1990 study. A total of 216 respondents provided responses in the following areas: visual complaints, helmet fit, and acoustics. Data indicated that 92% of respondents reported at least one visual complaint either *during* or *after* IHADSS flight. Additional findings included: no association between eye preference and frequency of complaints, an increase in frequency of visual complaints from the 1990 study (Behar et al., 1990), and no correlation between frequency of visual complaints and age or experience.

Because all of the studies discussed above were conducted in relatively benign environments (e.g., training and non-combat missions), there had been concerns that the severity and frequency of the problems reported under such peacetime conditions would increase dramatically under the increased stress of an operational combat environment. In 2003, Operation Iraqi Freedom (OIF) provided the opportunity to investigate these concerns. A new survey study was conducted in northern Iraq over a 3-day period, 25 to 27 November 2003 (Hiatt et al. 2004). The survey consisted of a written questionnaire and an oral interview. The relevant section of the questionnaire was a set of questions regarding visual complaints, symptoms, and illusions experienced either *while* or *after* flying with the IHADSS under combat conditions. To allow comparison with previous survey data, the study questionnaire was modeled after the corresponding section of the 2000 survey (Rash et al., 2001). In general, the 2003 OIF study failed to find any increase in reports of visual problems and instead found statistically significant lower reported incidence of most problems and complaints. Post hoc discussions with Apache

pilots suggested that the limited flight hours allowed in peacetime flying forced pilots to make a conscience effort to "fly the (IHADSS) system," causing greater visual strain and discomfort. This constraint was not present in the OIF study as ample flight hours were available to pilots.

In summary, while visual complaints persist, to a greater of lesser extent, the early major concerns of a monocular HMD design have not been shown to significantly degrade pilot flight performance or safety. An analysis of AH-64 Apache accidents using accident investigation data from the U.S. Army Risk Management Information System (RMIS)[4] for the period October 1985 through March 2002 found that accidents in which the IHADSS/FLIR system was identified as the major casual factor represented less than 1% of all AH-64 accidents and only 2% of accidents where IHADSS use was identified (Rash et al. 2003).

However, for the period covering the early fielding of the Apache AH-64 in the U.S. Army, one concern had not been investigated by any of conducted studies: the possible residual impact of the long-term use of a monocular optical design HMD on visual performance, especially binocular performance.

From 2000-2001, the initial fielding of the Apache AH Mk 1 with the IHADSS HMD by the British Army Air Corps offered a newly exposed population (cohort)[5] that could carefully be studied for potential long-term effects due the use of the IHADSS monocular design, the findings of which would be useful for both the British and U.S. AH-64 communities.

Consequently, the principal aim of this occupational health study was to determine if the use of the *monocular* HMD in the British Army's Apache AH Mk 1 attack helicopter has any long-term effect on visual performance. For a control group, the study used all other British pilots not flying the AH Mk 1 but who use a *binocular* HMD, the image-intensification-based night vision goggles (NVGs) (figure 3).

Figure 3. Binocular night vision goggles (NVGs) worn by control (non-Apache) subjects.

[4] The RMIS database is maintained by the U.S. Army Combat Readiness Center (USACRC) (formerly the U.S. Army Safety Center), Fort Rucker, AL.
[5] In statistics, a *cohort* is a group of subjects who have shared a particular event together during a particular time span, e.g., pilots who fly the Apache AH Mk 1 using the monocular IHADSS HMD.

An initial report described the study's protocol, methodology, development, and initial execution phase in detail (Hiatt et al., 2002). A series of interim reports have documented the progress of this study:

- USAARL Report No. 2002-04, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Initial Report," (Hiatt et al., 2002a).
- "Cohort Vision Study of Apache AH Mk 1 Pilots: Protocol and Methodology," (Hiatt et al., 2002b).
- USAARL Report No. 2004-18, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Two-Year Baseline Review," (Rash et al., 2004).
- "Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A 10-Year Prospective Cohort Study of Apache AH MK 1 Pilots-A Four-Year Update," (Adams et al., 2008).
- USAARL Report No. 2010-09, "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Four-Year Review," (Rash et al., 2010).
- "The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Study Midpoint Update," (Hiatt et al., 2009).

Due to loss of key U.S. personnel, an 8-year interim report was not published; however, a data review was performed by the U.S. Aeromedical exchange flight surgeon to fulfill duty-of-care obligations to ensure subject health and safety.

The current and final report presents the longitudinal data analysis for visual performance data[6] for the full 10-year period January 2000 to July 2010.[7] Visual performance data are examined for within- and between-subject differences for 116 subjects: 35 exposed (AH Mk 1), 70 control,[8] and 11 conversion[9] subjects.

Division of study responsibilities

Study responsibilities were divided between two actively participating organizations: The Headquarters Director Army Aviation (HQ DAAvn),[10] Middle Wallop, United Kingdom, and the U.S. Army Aeromedical Research Laboratory (USAARL), Fort Rucker, AL, United States. Subject recruitment, questionnaire administration, and eye exams were conducted in the United

[6] Data for non-visual performance parameters, e.g., helmet use, and head and neck pain are reported separately (Walters et al., 2013).
[7] The collection of data was suspended during the first year of the study due to late delivery of aircraft, during which no Apache flight hours were logged.
[8] Control subjects flew non-Apache aircraft, e.g., the Westland Gazelle, the Squirrel and the Lynx Mk 7/9.
[9] A conversion subject is defined as an initially enrolled control subject who during the period of the study transitioned into the AH Mk 1 Apache aircraft.
[10] HQ DAAvn is currently the Headquarters Army Air Corps (HQ AAC).

Kingdom by the assigned U.S. Army Medical Corps Aviation Medicine Exchange Officer[11] (Apache Systems) at various United Kingdom Army air base locations, but primarily at Middle Wallop. Data analyses were conducted at USAARL. Reports were written jointly by the U.S. principal investigator and one or more of the Aviation Medicine Exchange Officers or British Specialists in Aviation Medicine (SAMs).[12]

Study design

General

A cohort of British Apache AH Mk 1 pilots (exposed group) and a control group of British Army helicopter pilots who do not fly the Apache AH Mk 1 were followed over a 10-year period. At yearly intervals, the subjects were asked to complete a questionnaire and undergo an expanded flight physical examination. The questionnaire addressed flight experience, vision history, disorientation, neck and back pain, helmet usage, contact lens use, and handedness.[13] The expanded physical examination consisted of a battery of vision tests designed to assess both monocular and binocular visual performance. The change in physiological state and symptomatology are to be compared between the control and exposed groups.

Subjects

Once the study protocol was approved (November 2000) and until the study midpoint (end of 5th year), all rated British Army pilots scheduled for transition to Apache AH Mk 1 training course were recruited as *exposed* subjects. The original study protocol anticipated a total recruitment of 80 exposed subjects by the midpoint of the study, the last year of planned enrollment.

All British Army pilots actively flying helicopters other than the Apache were recruited as *control* subjects. The original study protocol anticipated a total recruitment of 300 control subjects by the midpoint of the study.

The study was designed to allow for cross-over (conversion) of control group subjects to the exposed group, i.e., pilots initially enrolled as controls but later were are selected for training as Apache AH Mk 1 pilots would be recruited for the exposed group and disenrolled from the control group. If they consented, their most recent data as a control subject would be considered their baseline data as an exposed subject. However, exposed subjects leaving the Apache airframe would be disenrolled completely from the study.

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[11] Over the 10-year course of the study, 6 U.S. Army Flight Surgeons served in this role.
[12] When required by logistical issues, British SAMs conducted study functions. A SAM is the United Kingdom equivalent to a U.S. Flight Surgeon.
[13] Handedness is a human attribute defined by unequal distribution of fine motor skills between the left and right hands.

A total of 229 subject numbers were assigned during the conduct of the study. The first subject was enrolled in November 2000[14] and the last subject in July 2006. Two subjects were inadvertently assigned double numbers due to changes in enrollment or enlisted/warrant/officer status (#37/#183 and #76/#192), leaving 227 unique subjects. Of these, 104 were not included in the final study analysis because only an initial eye examination was performed. An additional four subjects were disqualified for reasons that included: three subjects that had neither received eye exams nor completed questionnaires (#129, #134 and #136); and one subject who was contaminated by flight with a non-Apache day/night monocular system (#190). One additional exposed subject (#101) was disqualified from the study due to having acquired only 1 month of Apache flight time. This reduced the subject total to 118. Of these, 35 were recruited as exposed subjects and 83 as control subjects.

Over the period of the study, 13 subjects initially enrolled as controls entered the Apache pilot training program (i.e., converted subject). Of these 13 converted subjects, one (#53), who initially was enrolled in 2001 as a control and converted, completed Apache training in 2003 but left the Apache program in 2009, returning to a non-Apache flight status. Because of limited data and delays in transitioning, it was decided to exclude this subject from the final data analysis. A second converted subject (#114) was enrolled as a control in 2002, underwent two eye examinations as a control, converted to the Apache program in March 2005, and underwent a final study eye examination in April 2005, with only one month of exposure to the Apache's monocular HMD. It was decided to discard this subject's last exam and treat as a control subject. This resulted in only 11 converted subjects included in the final analysis.

In summary, there were a total of 116 subjects included in the final analysis: 46 exposed subjects (including 11 converted) and 70 control subjects.

Timeline

The execution of the study was initially delayed due to delays in both the initial military airworthiness release of the airframe and the delivery of the Apache Full Mission Simulator, which directly affected the training program. The study start was not implemented until mid-2000, with the first subject being recruited in November 2000. A timeline of the study is provided in table 1.

Ethical considerations and safety

Medical screening

All British Army pilots awarded an unrestricted flying medical category (A1 or A2) at their annual aircrew medical examination were deemed medically qualified to participate in this study. No further medical screening was required. All subjects had the objectives and procedures of the study explained to them, and were encouraged to ask questions. If willing potential subjects

[14] While the first subject (Subject #1) was enrolled and completed the questionnaire in November 2000, the subject's first eye exam was not conducted until March 2001.

were to participate, they were asked to sign a consent form (appendix A), which is kept on file. They were informed of their right to withdraw from the study at any time.

Confidentiality

All subjects were assigned a number that was used to identify their data (eye examinations and questionnaires). No individual has been, or will be, identified by name in any publication or presentation.

Table 1.
Study timeline.

Phase	Dates	Objective	Execution
ONE	1998 to 2000	Protocol development and approval	Completed 2000
TWO	2000 to 2001	Initial report – Study purpose and scope	Completed 2001; USAARL Report No. 2002-04, “The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Initial Report,” (Hiatt et al., 2002a).
THREE	2000 to 2006	Subject enrollment	A total of 227 subjects enrolled over the period of November 2000 to July 2006
FOUR	2000 to 2008	Biennial interim reports	
	2000 to 2002	2-year report	USAARL Report No. 2004-18, “The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Two-Year Baseline Review” (Rash et al., 2004)
	2003 to 2004	4-year report	USAARL Report No. 2010-09, “The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Four-Year Review.” (Rash et al., 2010)
	2005 to 2006	6-year report	“The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of Apache AH Mk 1 Pilots, Study Midpoint Update,” (Hiatt et al., 2009).
	2007 to 2008	8-year report	Due to loss of key U.S. personnel, an 8-year interim report was not published; a data review was performed by the U.S. Aeromedical exchange flight surgeon to fulfil duty-of-care obligations to ensure subject health and safety.
FIVE	2010	10-year final report	Completed December 2014.

Hazards and precautions

All tests performed on subjects in this study were free from discomfort or risk of injury. Similar or identical tests are part of the existing annual aircrew medical examination or are part of standard optometric evaluations. No specific precautions were necessary as there were no significant hazards or risks to the subjects, other than those associated with normal operational flight. Trained medical professionals who were specifically briefed on the study methods and objectives conducted all testing.

There was a small increased risk to British Army pilots of medical disqualification from flying as a consequence of this study, as several tests of visual function were added to the annual aircrew medical examination, and others were performed more frequently. However, aircrew medical standards were not being changed, and all these aspects were explained in the consent form.

Limits

If at any time during the study, a subject requested to leave the study, or if the medical or scientific supervisors determined it necessary, the subject's participation in the study was terminated. All data obtained prior to disenrollment were eligible for inclusion in the final analysis. Other potential reasons for termination were: 1) subject ceased to fly helicopters for a period longer than 2 years; 2) subject left military service; or 3) an exposed subject left the AH Mk 1 flight program.

Medical responsibility

A supervising medical officer provided medical oversight during the study. As there were no safety or medical risks to the subjects, no formal medical monitor was necessary. The supervising medical officer was one of the following: Consultant Adviser (CA) Avn Med, HQ DAAvn or U.S. Army Aviation Medicine Exchange Officer, HQ DAAvn.

Materials and methods

The study consisted of a number of optometric and anthropometric measurements (objective measures), as well as a series of questionnaires (subjective and self-reported measures) that were administered to both the exposed and control groups. Demographic forms (appendix B) were completed for each annual exam.

Optometric measures

The expanded optometric measurements were administered to both groups in conjunction with scheduled annual flight physicals. When this was not possible, subjects were evaluated at times as close to the annual periods as could be arranged based on deployment and assignment status. All tests of visual performance were conducted monocularly and binocularly except where contraindicated (e.g., in eye dominance testing). Visual acuity and contrast sensitivity were

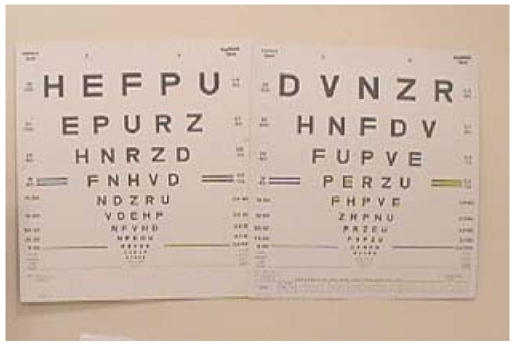
measured with the subject's habitual vision correction (spectacles or contact lenses) if the subject presented with correction at the time of the examination. The expanded optometric examination visual test parameters, test equipment and brief methodologies are provided in table 2. The various test equipment are shown in figure 4. Measured eye exam data were recorded on a paper form developed for the study (appendix C).

Table 2.
Visual test parameters, equipment and methodology.

Test parameter	Equipment	Methodology
Refractive error (spherical equivalent)	Model AR-600, Nidek Autorefractor	Subject views into autorefractor; spherical and cylindrical power averaged over three readings.
High contrast visual acuity (HCVA)	Bailey-Lovie high contrast visual acuity chart	Subject reads letters, continuing as far down the chart as possible; the measured data value is the total number of incorrect (unreadable) letters.
Low contrast visual acuity (LCVA)	Bailey-Lovie low contrast visual acuity chart	Subject reads letters, continuing as far down the chart as possible; the measured data value is the total number of incorrect (unreadable) letters.
Small letter contrast sensitivity	Rabin Small Letter Contrast Test (SLCT) (Rabin and Wicks, 1996)	Subject reads letters, continuing as far down the chart as possible; the measured data value is the total number of incorrect (unreadable) letters.
Depth perception (Stereopsis)	Stereotest-Circles test	Wearing polarized glasses, subjects view arrangements of three circles and indicate which circle in each group of three appears closest.
Color perception	Lanthony desaturated D-15 hue test (Lanthony, 1986)	Subject arranges the color chips in order according to color starting with a base/fixed cap.
Accommodation	Prince rule	Subject movies small-print target on the Prince Rule slowly away from each eye in turn, noting when the letters on the target can be read.
Eye muscle balance (Far and near distances)	Optec® 2000 Vision Tester	Subject is measured for both a far (6 m [20 ft]) and near (~½ m [18 in]) distance condition.
Eye dominance	Dolman method hole test (Cheng et al., 2004)	Subject views the examiner's head through a hole in a card, and then closes each eye alternately allowing the examiner to determine which eye is being used by the subject for sighting. The test is repeated four times, and the predominant eye is recorded.

To minimize disruption of pilot duties and reduce logistics the U.S. aeromedical exchange flight surgeon attempted to perform eye exams mainly at the British Army base in Middle Wallop, United Kingdom, where the initial Apache training is conducted. Alternatively, and especially for control subject eye exams, it was necessary to travel to other bases. In addition, on rare occasion, British flight surgeons performed the exams at remote locations.

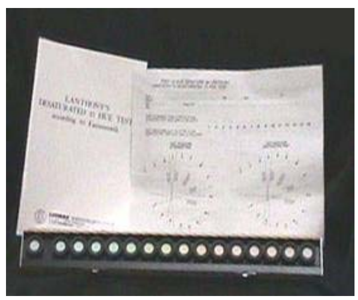
a. Autorefractor



b. Bailey-Lovie Visual Acuity Charts

c. Rabin SLCT Chart

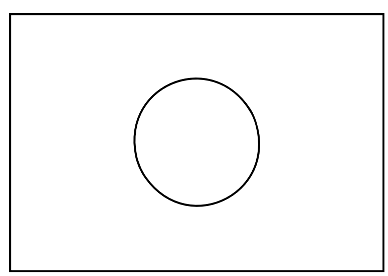
d. Stereotest-Circles Test



e. Lanthony Desaturated D-15 Hue Test

f. Prince Rule

g. Optec® 2000 Vision Tester



h. Card with hole

Figure 4. Equipment used in optometric tests.

To facilitate these alternative test sites, remote test kits and testing instruction booklets were developed by USAARL. These kits contained all of the equipment needed for eye exams except for the autorefractor and automated Vision Tester.

Refractive error

Each subject's refractive error was measured monocularly using an autorefractor (figure 4a).[15] A single reading was taken for each eye during an exam. Each recorded measurement consisted of a sphere, cylinder and axis value.

High-Low contrast visual acuity

High-contrast and low-contrast static visual acuity was measured using Bailey-Lovie charts (figure 4b), which allow the expression of acuity as the logarithm of the minimal angle resolved (log MAR) and the scoring of acuity is more continuous than with conventional Snellen charts (Bailey and Lovie, 1976). These tests consist of 14 gradually smaller rows of five letters each.

Contrast sensitivity

The Rabin Small Letter Contrast Test (SLCT) chart (figure 4c) that presents different letters with decreasing levels of contrast was used as a measure of small letter contrast sensitivity. This method has been shown to be sensitive to small changes in visual performance. The test was developed by USAARL (Rabin and Wicks, 1996).

Depth perception (Stereopsis)

Stereo vision was measured using the Stereotest-Circles test[16] (Stereo Optical Co., Inc., figure 4d). Subjects viewed arrangements of three circles through polarized spectacles and determined which circle in each group of three appeared closer than the others. The task becomes progressively more difficult with each successive arrangement.

Color perception

The Lanthony desaturated D-15 hue test (figure 4e), adapted from the Farnsworth (1947) panel D-15 was used to assess color vision. This test consists of 16 color chips/tabs selected from the Munsell (1929) book of color that are desaturated and appear pale and light. The subject's task is to arrange the color chips in order according to color. If deemed necessary in order to compare small differences in performance, a modified Farnsworth-Munsell (1943) FM-100 test quantitative scoring scheme was available. An error score is calculated from the selected sequence of color tabs.

Accommodative function

In the normal aircrew medical examination, this ability is measured in a binocular fashion, stimulating convergence and accommodation together by maintaining focus and fusion on a target. In this study, accommodation was tested monocularly using a Prince Rule (figure 4f), where a small print target was moved slowly away from each eye in turn, with the observer noting when the subject could read the letters on the target.

Eye muscle balance

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[15] Model AR-600, Nidek Co., LTD., Tokyo, Japan.
[16] Stereo Optical Co., Inc., Chicago, IL.

The eyes are held in place by three pairs of muscles that constantly balance the pull of the others. These muscles work together to move the eyes in unison, which allow the eyes to track moving objects. Binocular vision is a consequence of the separation of the eyes, which results in two views of the scene. To prevent double vision (diplopia), the eye uses a movement called "vergence." The eyes turn to direct the images directly onto the retina. The brain fuses these two images into one. When both eyes fail to point to the same location in space, a condition known as heterotropia or strabismus exists (i.e., a tendency of the two eyes to deviate from the parallel).

The study initially used a Maddox rod test to quantify any heterophoria (figure 5). A Maddox rod actually consists of a series of thin red cylinders placed side by side, usually mounted in a circular holder that can be held before the eye. A set of prisms are used to measure the amount of vertical and/or horizontal phoria present. This is a very complex and time-consuming test and measurements are highly subject to error when not administrated by non-optometric personnel. As a consequence, in the second year of the study, a recommendation was made by the then U.S. medical exchange officer serving as the test administrator to replace the Maddox rod test with an automated Optec® 2000 Vision Tester (figure 4g).

Figure 5. The Maddox rod test.

Eye dominance

A test of sighting preference (dominance) was used, as this has been shown to correlate well with other dominance measures (Behar et al., 1990). The test is called the Dolman method "hole" test (figure 4h), in which the subject views the examiner's head through a hole in a card, then closes each eye alternately to determine which eye was used for sighting (Cheng et al., 2004). The test was repeated four times in an exam.

Subjective measures

Upon entry to the study, each subject completed a subject consent form (appendix A), a demographic form (appendix B), and either an annual questionnaire for non-Apache (control) pilots (appendix D) or for Apache (exposed) pilots (appendix E). These latter questionnaires addressed flight experience, vision history, disorientation, neck and back pain,[17] and helmet usage. For those individuals who wore soft contact lenses during flight, an additional questionnaire was provided (appendix F). Finally, all subjects were asked to complete the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971), a 10-item measure of laterality (handedness) (appendix G).

Analysis approach

This study is considered to be longitudinal in nature. Longitudinal data result from observing subjects on a number of parameters over time (Bijleveld et al., 1998). This description implies a repeated measures design, i.e., observations are made on a certain number of occasions. One rationale for a longitudinal study is to investigate change in one or more parameters over time. In this study, there are multiple parameters associated with visual performance, e.g., visual acuity, color discrimination, eye dominance, and contrast sensitivity.

Longitudinal studies can examine both *intra*-individual (within-subject) and *inter*-individual (between-subject) changes over time. Detecting the presence of intra-individual changes in these parameters for AH Mk 1 pilots exposed to long-term use of the monocular HMD was the overall goal of this study. Inter-individual changes are examined by comparing data for AH Mk 1 pilots to a control sample of non-AH Mk 1 military pilots. A general assumption of longitudinal studies is that observations over time are equally spaced. This study attempted to collect subject data on a yearly basis. This proved to be a difficult challenge, as access to pilots frequently was complicated by unanticipated deployments that proved to be geographically difficult to overcome. For exposed subjects, actual measurement periods between eye exams ranged from 5 to 83 months with an average and *Mdn* of 24 and 21 months, respectively. For control subjects, actual measurement periods ranged from 8 to 98 months with an average and *Mdn* of 30 and 18 months, respectively.

Another assumption of standard statistical tests commonly applied to longitudinal data is independence, i.e., subsequent measurements are not dependent upon previous measurements. In fact, in this study, successive measurements are serially dependent, which invalidates many statistical methods. This issue is addressed in this analysis through the use of paired-sample *t*-tests, based on the first and last available exam data points for each subject.

An additional issue associated with these data collected within this study is that of random sampling. Longitudinal studies often are unable to achieve random sampling due to their inherent nature. This was a special consideration is for the exposed subject group of AH Mk 1 pilots. This group was extremely limited in number and geographically scattered due to deployments in Ireland, Iraq, and Afghanistan. This resulted in significant difficulty in obtaining annual data. Therefore, the exposed sample was influenced by limited population size and subject availability.

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[17] To be addressed in a separate report.

Between-subject analyses were performed first. For some test parameters, if no statistically significant difference was found between exposed and control groups, within-subject analyses were not performed. However, where deemed appropriate and especially for eye examination data, paired-samples *t*-tests were performed, where the first and last available exam data values for each subject over individual exposure periods served as the *t*-test data pairs. The *p*-value was set at the $p < 0.05$ level. In all analyses involving *t*-tests, tests were conducted as 2-tailed and assuming unequal variances. Chi-square analyses were used to compare distribution of multiple response questions in the annual questionnaire.

Data management

As eye exam data record forms and annual questionnaires were completed, originals were forwarded to USAARL on a semi-annual schedule for data analysis. Copies were maintained in Middle Wallop, United Kingdom, by the U.S. aeromedical exchange officer. As the data collected for the study were medical in nature and included biographical data, they were treated and stored as any other medical record with regard to confidentiality.

Demographics

Age and gender

The 46 exposed and converted subjects used in the final analysis were all male (100%) and ranged in age (at first exam date) from 23 to 47 years, with a mean (*M*) and median (*Mdn*) of 34 and 35 years, respectively (table 3). The 70 control subjects were predominantly male (96%) and ranged in age (at first exam date) from 22 to 49 years, with a *M* and *Mdn* of 31 and 29 years, respectively. The difference between the exposed and control *M* age was found to be statistically significant ($p = 0.007$). The trend of slightly higher *M* (34 years for exposed subjects versus 31 years for control subjects) and *Mdn* ages (35 years for exposed subjects, versus 29 years for control subjects) reflects the fact that most of the pilots selected for initial transition into the Apache were older, more experienced pilots.

Due to the very small presence of females in the study (exposed – 0%; control – 4%), the final analysis did not perform any comparisons of performance by gender.

Flight experience

Flight experience, based on total flight hours, was obtained via annual questionnaires. Due to geographical challenges and time constraints, there was not always a one-to-one correspondence between questionnaires and eye exams. Consequently, data for total flight hours, flight hours flown during the study, and NVD flight hours flown during study are underreported.[18] However,

[18] 19% of control subjects' eye exams and 27% of exposed subjects' eye exams did not have corresponding questionnaires; and some questionnaires did not contain all flight hour data. However, for some subjects, flight hour

these data do provide an approximation of the level of flight experience for subjects upon enrolling in the study as well as for flight hours flown during the study.

Total flight hours reported by control subjects (upon enrollment into study) ranged from 80 to 7,400, with a *M* and *Mdn* of 898 and 200, respectively. As a group, control subjects accumulated a total of at least 26,862 flight hours during participation in the study, ranging individually from 30 to 4050, with a *M* and *Mdn* of 597 and 350, respectively.[19]

For exposed (and converted) subjects, total flight hours (upon enrollment into study) ranged from 220 to 4,850, with a *M* and *Mdn* of 2,405 and 2,495, respectively. As a group, exposed (and converted) subjects accumulated a total of at least 21,184 flight hours during participation in the study, ranging individually from 45 to 1,810, with a *M* and *Mdn* of 584 and 503, respectively. [20]

Table 3.
Study demographics.

	Sample size (n)	**Gender**	**Age[21] (Years)**	**Total flight hours[22]**	**Flight hours during study**	**Night vision device[23] flight hours during study**
Exposed[24]	46	Male: 46 (100%) Female: 0 (0%)	Min: 23 Max: 47 *M*: 34 *Mdn*: 35	Min: 220 Max: 4,850 *M*: 2,405 *Mdn*: 2,495	Min: 45 Max: 1,810 *M*: 584 *Mdn*: 503 Total: 22,184	Min: 10 Max: 1,810 *M*: 592 *Mdn*: 500 Total: 21,892
Control	70	Male: 67 (96%) Female: 3 (4%)	Min: 22 Max: 49 *M*: 31 *Mdn*: 29	Min: 80 Max: 7,400 *M*: 898 *Mdn*: 200	Min: 30 Max: 4,050 *M*: 597 *Mdn*: 350 Total: 26,862	Min: 3 Max: 200 *M*: 49 *Mdn*: 37 Total: 2,713
Significance			$\boldsymbol{p = 0.007}$	$\boldsymbol{p < 0.0001}$	$p = 0.919$	$\boldsymbol{p < 0.0001}$

Total flight hours flown using the binocular NVGs reported by control subjects while enrolled in the study ranged from 3 to 200, with a *M* and *Mdn* of 49 and 37, respectively. As a group, control subjects accumulated a total of at least 2,713 NVG flight hours during participation in the study. Exposed (and converted) subjects reported accumulating a total of 21, 892 flight hours

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data could be extrapolated if a final questionnaire was available. Overall, flight hour data were underreported for 21% of control subjects and 17% of exposed subjects.

[19] Flight hour data not available, due to failure of subjects to complete questionnaires, were not included in statistics.

[20] Flight hour data for converted subjects were computed from date of conversion; flight hour data not available, due to failure of subjects to complete questionnaires, were not included in statistics.

[21] Age data are based on age at first eye exam.

[22] Total flight hours upon entering study. These data were acquired from questionnaires; the date of first completed questionnaire did not always coincide with date of first eye exam.

[23] For exposed subjects, the night vision device is the monocular IHADSS; for the control subjects, the NVD is the binocular NVGs.

[24] Includes converted subjects.

using the monocular IHADSS NVD during the study. These IHADSS flight hours ranged from 10 to 1,810, with a *M* and *Mdn* of 592 and 500, respectively.

The differences between the means for the exposed and control groups were significant ($p < 0.0001$) for total flight hours at time enrollment in study and NVD flight hours flown during the study; the difference in means for total flight hours flown during the study was not significant ($p = 0.919$).

The large disparity between NVD total exposure of exposed subjects (Apache pilots using the IHADSS) and the control subjects (using NVGs) was mostly due to two factors. First, several of the exposed subjects were Apache instructor pilots (IPs), who would amass significantly higher number of flight hours than the typical subject. Second, most of these IPs were the first enrollees in the study and participated in the study for substantially longer periods of time.

Across the full study, exposed subjects participated in the study for periods that ranged from 5 to 124 months with a *M* and *Mdn* of 43 and 39 months, respectively; control subjects had periods of participation that ranged from 8 to 115 months with a *M* and *Mdn* of 45 and 42 months, respectively. The difference between the means was significant ($p = 0.675$).

Underreported flight hour data due to unavailable questionnaires preclude rigorous statistical comparisons between groups for some parameters. However, these data do characterize the exposed subjects to be more experienced (i.e., having greater total flight hours upon entry into study), supported by the aforementioned fact that the pilots selected for initial transition into the Apache were older, more experienced pilots.

Data and between-subject analyses

The following sections present those data considered most pertinent to the primary design goal of the study, i.e., an investigation of visual effects. Between-subject analyses were conducted for 46 exposed (and converted) and 70 control subjects for their periods of participation over the 10-year study. Only vision and vision-related data are reported herein. Except where noted, percentages in the sections below are based on the proportion of subjects who provided responses to the individual questions or for whom visual test measurements were obtained. To facilitate linking presented data to the various questions in the questionnaires, data values presented in the following sections are referenced to the associated question number (see appendix D for the Non-Apache (Control) subject annual questionnaire and appendix E for Apache AH Mk 1 (Exposed) subject annual questionnaire. Only data in response to vision-related sections of the questionnaire are reported here.

Annual questionnaire

Vision history

Vision correction

Of the 70 control subjects, 34% (24) reported that they had been prescribed vision correction (Question 10a) via spectacles; and 7% (5) had been prescribed contact lenses (Question 11). Optical correction data were available for 45 of the 46 exposed subjects; of these 45 subjects, 31% (14) reported that they had been prescribed spectacles (Question 10a), and 16% (7) had been prescribed contact lenses (Question 11). Respondents cited reading and flying tasks as the most common use of corrective devices (Question 10b). A 2x3 Chi-Square (2-tailed, Fisher Exact test) analyses of these data find no significant differences between exposed and control groups for the distribution of proportions for vision correction requirements (i.e., no correction or wearing either spectacles or contact lenses ($p = 0.355$).

Sighting eye preference

The questionnaires for both control and exposed subjects posed three questions (Questions 17 through 19) with regard to sighting preference for performing certain visual tasks. A fourth question (Question 20) asking if the preferred eye had changed during participation in the study was asked only of exposed (Apache pilot) subjects.

Sixty-five *control* subjects completed one or more questionnaires providing responses for preferred sighting eye (Question 17). Of subjects responding, 75.4% (49) reported their right eye and 23.1% (15) reported their left eye as their preferred sighting eye; 1 control subject (1.5%) reported no preference (figure 6). Sixty-nine control subjects provided responses for the specific viewing tasks of sighting with a telescope and viewing through a keyhole (Questions 18 and 19, respectively). Of subjects responding, 85.5% (59) indicated right eye preference for both viewing tasks; 13.0% (9) indicated left eye preference. One control subject (1.4%) reported no preference.

Sixty-one (87.1%) responding control subjects were unwavering across responses to the three sighting eye preference questions. Of these, 53 (86.9%) were right dominant in eye preference.

Forty-four exposed subjects completed all three questions regarding eye preferences. Of these, 84.1% (37) reported their right eye as their preferred sighting eye (Question 17); 11.5% (5) reported their left eye and 4.5% (2) were undecided (figure 6). For the specific viewing tasks of sighting with a telescope and viewing through a keyhole (Questions 18 and 19), 95.5% (42) and 93.2% (41) indicated right eye viewing preference, respectively. Left eye preference for these tasks was 4.5% (2) and 6.8% (3), respectively.

Forty (90.9%) of responding exposed subjects were unwavering across responses to the 3 sighting eye preference questions. Of these, 38 (95.0%) were right dominant in eye preference.

A chi-square analysis found no significant difference between sighting eye preference distributions for the exposed and control subjects ($p = 0.22$).[25]

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[25] The Yates' correction for continuity is often employed to improve the accuracy of the using the sampling distribution of chi-square as an approximation of binomial frequencies. The effect of Yates' correction is to prevent overestimation of statistical significance for small data sets. However, in some cases, it may overcorrect.

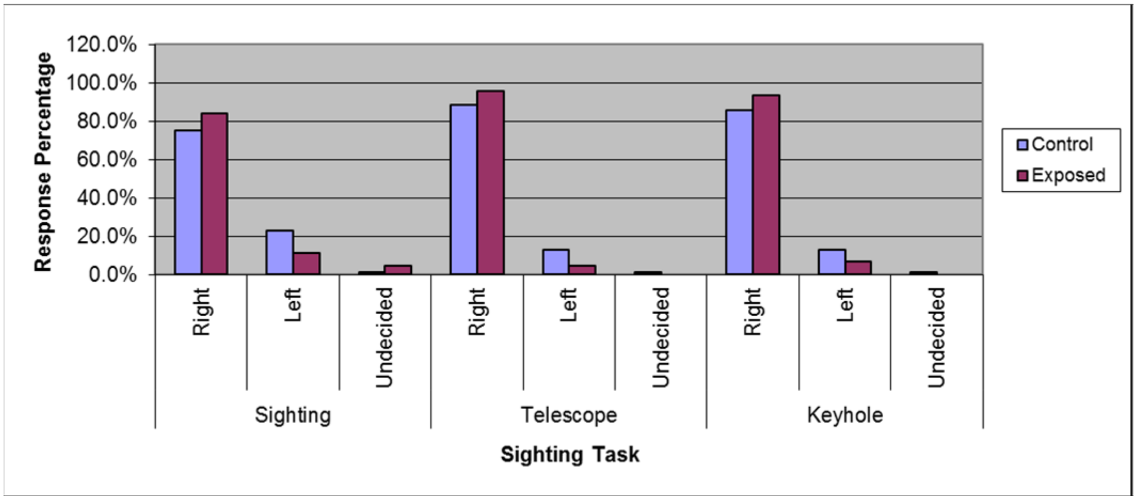


Figure 6. Control and exposed subjects' eye sighting preferences.

When exposed subjects were asked if their "preferred eye was the same one (currently) as prior to AH Mk 1 training (Question 20)," 95.2% (40) of responses were predominantly "Yes;" 4.8% (2) were undecided. Four subjects did not provide responses. One exposed subject who responded to Question 20 over a 5-year period did indicate on his final questionnaire that his preferred eye had changed (right to left). However, none of his other associated eye preference data over the period supported this response.

Visual problems

Flight-related visual symptoms

Flight-related visual/physiological symptoms experienced both *during* and *after* flight were reported for both control and exposed subjects via Questions 21 and 22 of the annual questionnaires. These questions queried the incidence of various previously-documented complaints, to include visual discomfort, headache, double vision, dizziness, and after images. Forced choice responses of "Never," "Sometimes," and "Always" were allowed.

When control subjects were asked to report on the presence of visual/physiological problems *during* flight (Question 21), disorientation (60% of responding subjects) and headache (58%) were the most frequently cited symptoms (table 4); *after* flight (Question 22), headache was the most frequently reported symptom (49%) (table 5). For all reported symptoms, the response was "Sometimes;"[26] no subject reported an "Always" response.

Table 4.

Reported visual/physiological symptoms *during* flight.

	Control (n = 65) / Exposed (n = 39)		
	Never	**Sometimes**	**Always**

[26] If a subject reported a symptom as "Sometimes" on any annual questionnaire, it was used as such in the analysis.

Visual discomfort	77% / 49%	23% /51%	0% / 0%
Headache	42% / 44%	58% / **56%**	0% / 0%
Double vision	100% / 95%	0% / 5%	0% / 0%
Blurred vision	92% / 82%	8% / 18%	0% / 0%
Afterimages	94% / 72%	6% / 28%	0% / 0%
Disorientation	40% / 64%	**60%** / 36%	0% / 0%
Dizziness	90% / 97%	10% / 3%	0% / 0%
Nausea	58% / 69%	42% / 31%	0% / 0%

Note: **Bold** values denote maximum percentages for subject group.

Table 5.
Reported visual/physiological symptoms *after* flight.

	Control (n = 67) / Exposed (n = 39)		
	Never	**Sometimes**	**Always**
Visual discomfort	85% / 74%	15% / 26%	0% / 0%
Headache	51% / 49%	**49%** / **51%**	0% / 0%
Double vision	99% / 95%	1% / 5%	0% / 0%
Blurred vision	97% / 90%	3% / 10%	0% / 0%
Afterimages	90% / 82%	10% / 18%	0% / 0%
Disorientation	99% / 95%	1% / 5%	0% / 0%
Dizziness	99% / 100%	1% / 0%	0% / 0%
Nausea	94% / 90%	6% / 10%	0% / 0%

Note: **Bold** values denote maximum percentages for subject group.

Exposed subjects reported headache (56% of responding subjects) and visual discomfort (51%), as the most frequently cited symptoms *during* flight (Question 21) (table 4) and headache (51%) as the most frequent *after* flight (Question 22) (table 5). For all reported symptoms, the response was “Sometimes;” no subject reported an “Always” response.

Headache was the most commonly reported symptom by both exposed and control subjects. For control subjects, headache was reported by approximately half of all subjects both *during* and *after* flight; disorientation (60%) was the most frequently reported symptom *during* flight for control subjects but was considerably less (36%) for exposed subjects. For exposed subjects, headache was the most frequently reported symptom both *during* and *after* flight, with visual discomfort ranked second for both *during* and *after* flight.

A Chi-square analysis was conducted to evaluate whether exposed subjects reported a different headache frequency than control subjects, either *during* or *after* flight. No statistically significant differences were found either *during* ($\chi^2 = 0.51$; $p = 0.610$) or *after* ($\chi^2 = 0.00$; $p = 1.00$) flight. However, similar tests found the greater frequency of disorientation symptoms for control subjects *during* flight ($\chi^2 = 5.67$; $p = 0.030$) and the greater frequency of visual discomfort symptoms for exposed subjects *during* flight ($\chi^2 = 8.68$; $p = 0.006$) to be significant. The difference in frequencies of visual discomfort *after* flight ($\chi^2 = 1.85$; $p = 0.269$) was not found to be significant.

Tables 4 and 5 summarize the reported symptoms for both *during* and *after* flight, respectively.

Eye fatigue

Viewing natural scenes is easy on the human visual system. However, prolonged viewing of displays, such as computer monitors, has resulted in reports of eye fatigue (McCown, 1999). Viewing imagery on HMDs is quite different from viewing the natural environment because an HMD is a display (Meltzer and Moffitt, 1997).

Viewing natural scenes with both eyes is an effortless and comfortable experience. This is because natural scenes have perfect alignment. Viewing imagery on binocular HMDs, e.g. NVGs, can result in the images seen by the two eyes having differences in magnification, brightness, distortion and vertical, horizontal, or rotational alignment. As a result, the left- and right-eye images can be different in multiple ways leading to eye fatigue (Melzer and Moffitt, 1997).

Control subjects were asked to what extent flying using NVGs caused eye fatigue (Question 25a) using a Likert scale (Not at all - Slight extent - Moderate extent - Great extent). Exposed subjects were asked the same question in two parts, one referring to day flight (Question 25a) and one referring to night flight (Question 25b). Because NVGs operate on the principle of light amplification, they can only be flown at night. However, the IHADSS uses thermal imagery and can be presented during both day and night flight; flight symbology can be displayed on the HDU also under all lighting conditions.

Of the 60 responding control subjects, 45 (75%) reported eye fatigue, to some extent, during night flight as a result of using NVGs (Question 25a); the largest response was “Slight extent” (58%) (figure 7). One subject (2%) reported experiencing NVG-caused eye fatigue to a “Great extent.”

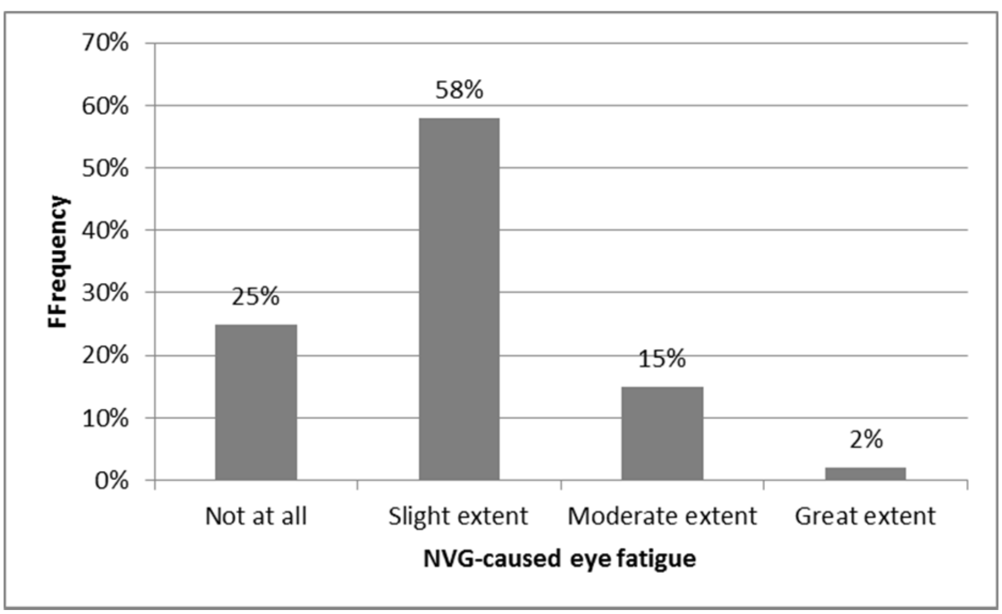


Figure 7. Degree of NVG-caused (Control) eye fatigue.

Of 38 responding exposed subjects 50% (38) reported eye fatigue, to some extent, during day flight as a result of using the PNVS/IHADSS system (Question 25a); the largest response was "Not at all" (50%). For night flight, reports for 36 responding subjects of eye fatigue to some extent increased to 86% (31); the largest response was "Slight extent" (58%) (figure 8).

A two-way contingency table analysis was conducted to test whether exposed subjects (86%) presented a different proportion of eye fatigue (to some extent) than control subjects (75%) during night flight (figure 9). No significant difference was found ($\chi^2 = 1.08$, $p = 0.299$).

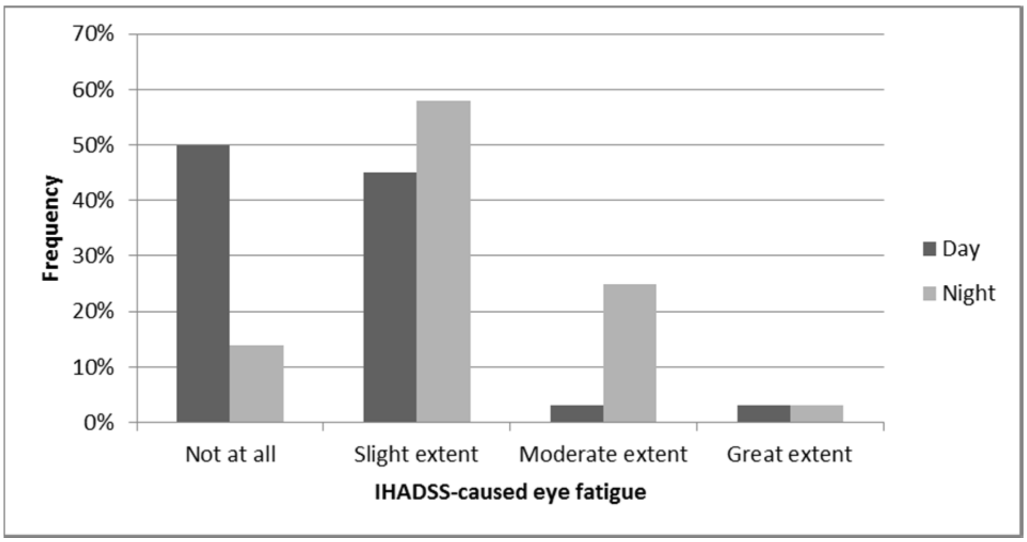


Figure 8. Degree of IHADSS-caused (Exposed) eye fatigue.

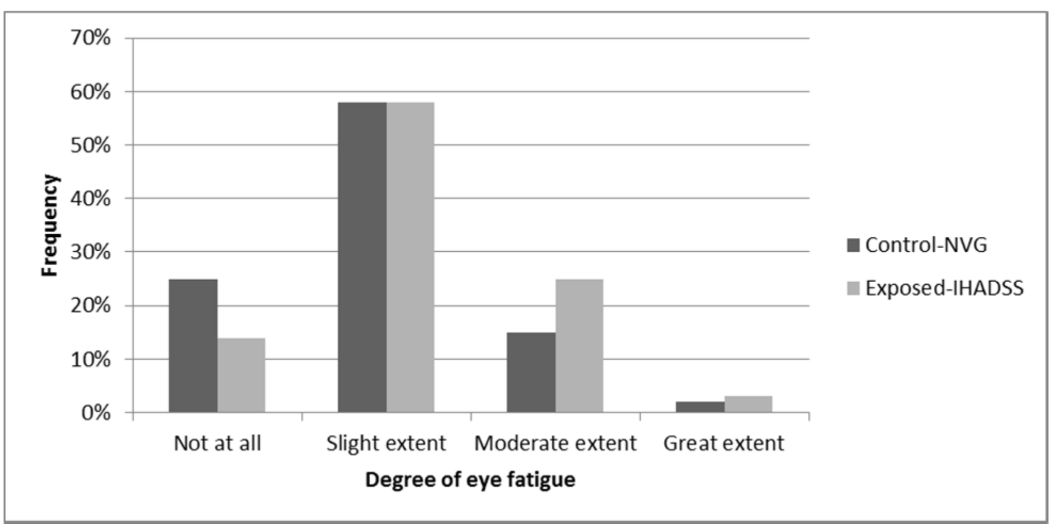


Figure 9. Comparison of eye fatigue, NVG vs. IHADSS (night flight).

Color adaptation

Of the 59 responding control subjects, 40 (68%) reported experiencing color perception problems after flying with NVGs (Question 29). Subjects reported a persistent "browned vision" for up to 15 minutes post-flight.

This problem first was raised in the early 1970s when an afterimage phenomenon was reported by U.S. Army aviators using NVG for night flights (Glick and Moser, 1974). It was initially, and incorrectly, called "brown eye syndrome." The reported visual problem was that aviators experienced only brown and white color vision for a few minutes following NVG flight. Glick and Moser (1974) investigated this report and concluded that the aviator's eyes were adapting to the monochromatic green output of the NVGs. When such adaptation occurs, two phenomena may be experienced. The first is a positive afterimage seen when looking at a dark background; this afterimage will be the same color as the adapting color. The second is a negative afterimage seen when a lighter background is viewed. In this case, the afterimage will take on the compliment color, which is brown for the NVG green. The final conclusion was that this phenomenon was a normal physiological response and was not a concern (Rash, 2000).

For exposed subjects, the IHADSS imagery also is considered monochromatic (single color), presenting a green image at the dominant wavelength of 543 nanometers (nm). Prolonged viewing of such an image can result in color adaptation that can temporarily affect color vision immediately following viewing, as experienced with NVGs. Fifty percent (19) of responding exposed subjects ($n = 38$) reported this phenomenon, again with most subjects reporting the effects disappearing in less than 15 minutes post-flight.

A two-way contingency table analysis was conducted to evaluate whether exposed subjects (50%) had a different proportion of color adaptation reports than control subjects (68%). No significant difference was found ($\chi^2 = 2.37$, $p = 0.091$). This finding might be expected since both NVG and IHADSS stimuli are provided by the same monochromatic phosphor (P-43), which is dominant in the green part of the visible spectrum.

Binocular rivalry (IHADSS)

While NVGs are a binocular system, the IHADSS system is dichoptic in nature, i.e., presenting two dissimilar images, one to each eye. The right eye views the HDU presentation of the FLIR imagery (and/or symbology), and the left eye views the cockpit interior or the outside world. This design can lead to a number of undesirable visual responses, including binocular rivalry and suppression (Klymenko and Rash, 1995). Binocular rivalry can cause unintentional alternation between different images presented to each eye.

Exposed subjects were asked to grade how frequently they experienced unintentional alternation both *during* and *after* flight using a 9-point Likert scale (1 - Never, 5 - 50% of the time, 9 - Always). *During* flight, 66% (24) of responding subjects reported experiencing unintentional alternation of visual inputs to some degree (Likert value > 1) (Question 27). A

histogram of individual *median* Likert scale value[27] responses is presented in figure 10; the *median* Likert value reported across all subjects *during* flight was 2, indicating minimal problems with unintentional alternation.

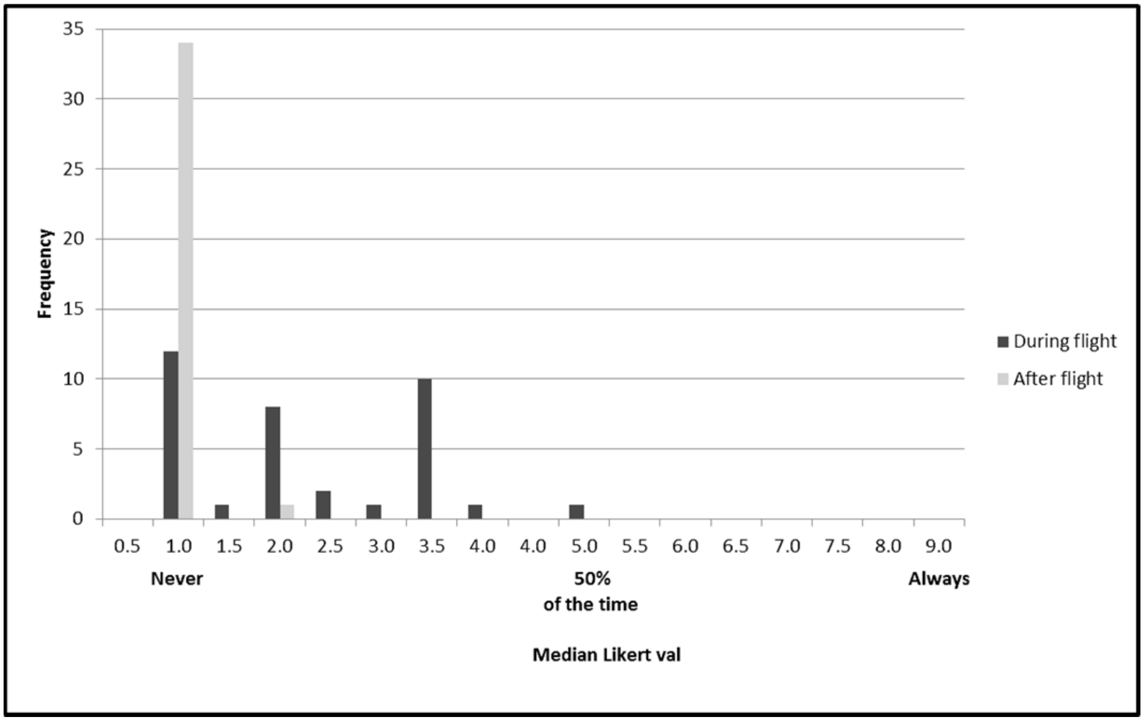


Figure 10. Histogram of exposed subject (IHADSS) individual *median* Likert scale values for unintentional alternation experienced *during* flight.

Only one subject reported a continuation of alternation symptoms *following* flight and then only to a minor degree (Likert value = 2) (Question 28).

Spatial disorientation

Spatial disorientation (SD) is defined in the United Kingdom as "a failure to perceive correctly one's position, motion or attitude with respect to the earth's surface (horizontal reference) or the acceleration due to gravity (vertical reference)" (Durnford et al., 1995).

With NVGs, SD can result from reduced visual acuity, reduced FOV, and reduced depth perception. These same factors can induce SD in flight with the Apache's IHADSS FLIR imagery presented on the HDU. And, since the IHADSS display is monocular, and the FLIR sensor is mounted on the nose of the aircraft (approximately 8 feet (ft) [2.4 meters (m)] forward of and 3 ft (0.9 m) below the pilot's design eye position), Apache pilots have additional factors that increase the potential for SD episodes.

[27] Likert scale data are ordinal (rank-ordered), where the rank values do not necessarily have equal intervals. Likert scale data are frequently described by the median, effectively the "middle" value.

Of the 59 responding control subjects, 17 (29%) reported having experienced SD during flight with NVGs (Question 32). Many of these occurrences were associated with episodes of "white out" or degraded NVG imagery. White out is a special condition where clouds of disturbed snow can obscure vision. A similar condition known as "brown out" is associated with clouds of dust.

For 37 responding exposed subjects, 32% (12) reported having experienced SD while flying with the IHADSS (Question 31). A few subjects reported SD experiences during the "bag phase" of initial Apache training as when the experience occurred. The bag phase refers to the period of flight training when the Apache student pilot is learning to use the IHADSS. Flights in this phase occur in daytime, with the student pilot's section of the aircraft (rear seat) fully enclosed (hence the use of the term "bag"), preventing any view of the outside world. However, when asked about SD episodes following the training period (Question 32), nearly the same proportion of responding subjects (11; 30%) reported such episodes.

A two-way contingency table analysis was conducted to evaluate whether exposed subjects have a different proportion (32%) of SD episodes than control subjects (29%). The greater proportion for exposed subjects was not found to be significant ($\chi^2 = 0.19$, $p = 0.663$). Following the completion of the "bag" phase of training, the percentage of exposed subjects reporting SD episodes decreased slightly to 30%. A two-way contingency table analysis found no statistical difference between the two proportions ($\chi^2 = 0.00$, $p = 1$).

Previous studies have indicated that while the IHADSS imagery is designed to be at optical infinity and of a 1:1 ratio with the outside world, pilots report problems with apparent size and distance of objects (targets) as viewed in the IHADSS imagery (Crowley, 1991; Hale and Piccione, 1990). While the majority of exposed subjects (74%; 26) reported objects to be "about the right size and distance;" 6% (2) reported them as "smaller and farther away;" 6% (2) reported them being "larger and closer than reality;" and 14% (5) reported varying perceptions of target size (Question 33).

Special exposed subject issue- IHADSS imagery

When using the IHADSS, flight imagery and symbology are presented on the HDU. Flight imagery is the picture of the outside world as produced by the nose-mounted FLIR sensor. Symbology is a set of alphanumeric and pictograms used to present flight information such as altitude, airspeed and heading.

Optically, the HDU imagery (FLIR scene and overlaid symbology) is at optical infinity. However, Apache pilots have reported both attention and accommodation issues in attending to the two components. Kotulak, Morse and Wiley (1994) showed that for some subjects knowledge of object distance is a more powerful cue for instrument accommodation than is the optical distance of the object. They also found that subjects whose accommodation is influenced by knowledge of object distance tend to have a more proximal dark focus than those whose accommodation is independent of knowledge of object distance. It was suggested that involuntary accommodation occurs when a transparency is superimposed between the observer and the object. In a broader interpretation, this situation may extend to the IHADSS FLIR

imagery with overlaid symbology. A condition known as instrument myopia is well known and associated with excessive accommodation when viewing with optical devices. The level of accommodation with such devices is known to be influenced by physiological factors, such as the viewer's dark focus point.[28] The contribution of psychological factors (e.g., knowledge of nearness of image source) to this condition is still debated.

Exposed subjects were asked to rate the frequency of having difficulty focusing simultaneously on both the FLIR imagery of the outside world and the HDU symbology, using a 9-point Likert scale (1 - Never, 5 - 50% of the time, 9 - Always) (Question 24). For 34 responding subjects, 32% (11) reported never having difficulty with focusing. A histogram of individual median Likert scale value responses is presented in figure 11. The *median* Likert value reported across all subjects was 2 (the *mean* of all individual subject medians presented in figure 11 is 2.2), indicating that Apache pilots, in general, did not experience a major difficulty with changing focus between the IHADSS FLIR representation of the outside scene and the presented flight symbology.

Integrally related to the question of switching focus for Apache/IHADSS pilots is the issue of switching attention between the two components of the imagery. Apache pilots historically have reported the need to purposely switch attention between the terrain FLIR scene and the symbology. To measure this cognitive necessity, exposed subjects were asked to rate how frequently this attention switching was performed *during* flight using a 9-point Likert scale (1 - Never, 5 - 50% of the time, 9 - Always) (Question 36).

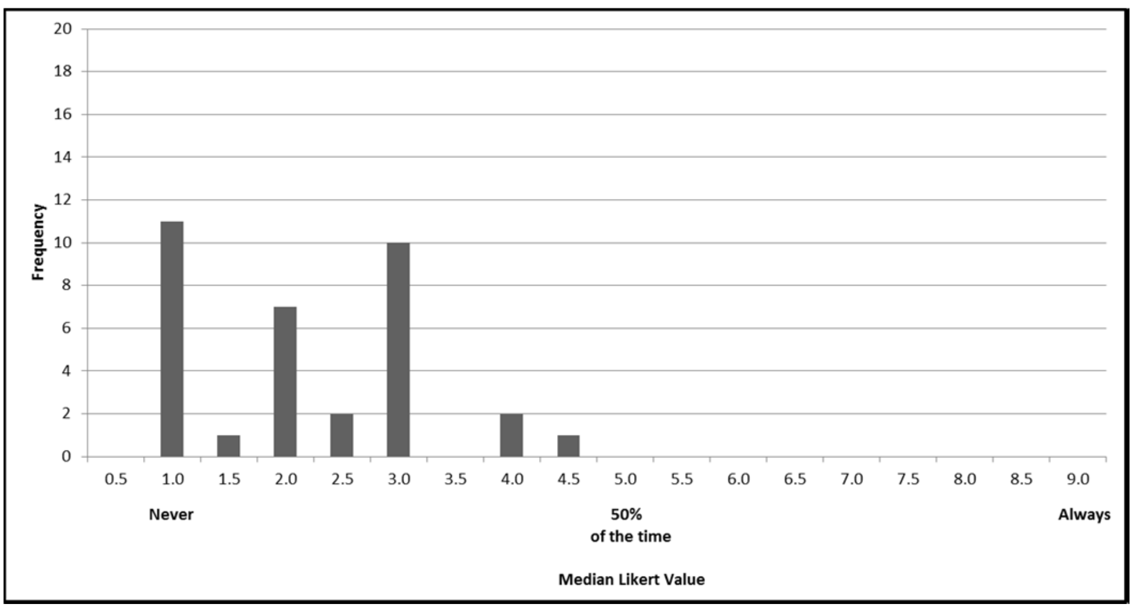


Figure 11. Histogram of exposed subject (IHADSS) individual *median* Likert scale values for difficulty in focusing simultaneously on FLIR and symbology imagery.

[28] The dark focus or resting state of visual accommodation is that refractive state to which the eye tends to return in the absence of any visual stimulus, as in complete darkness.

Of the 35 responding exposed subjects, 89% (31) reported the need to make, to some extent, an intentional cognitive effort to switch attention between the displayed FLIR scene imagery and symbology (Likert value > 1) (Question 36). A histogram of individual *median* Likert scale value responses is presented in figure 12. The *median* Likert value reported across all subjects was 4 (the *M* of the individual subject *medians* presented in figure 12 is 4.2).

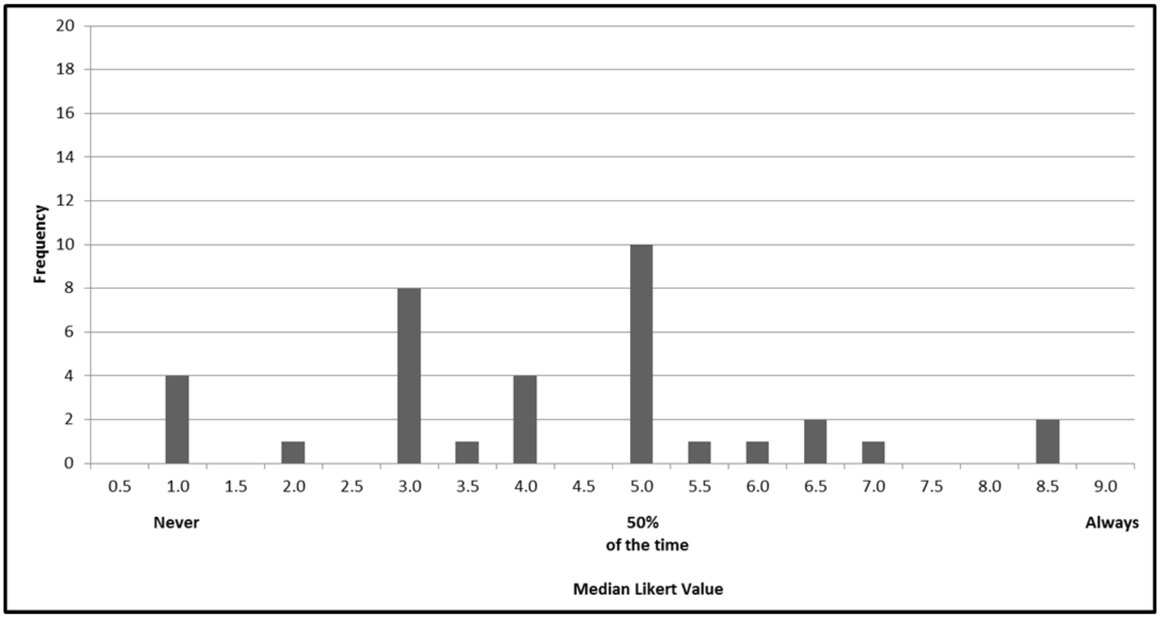


Figure 12. Histogram of exposed subject (IHADSS) individual *median* Likert scale values values for attention switching between terrain FLIR scene and flight symbology.

While flight imagery is presented egocentrically in front of the right eye, the imagery actually originates from the PNVS nose-mounted FLIR sensor located 8 ft (2.4 m) forward and 3 ft (0.9 m) below the pilot's design eye position. Brickner (1989) and Rash (2000) suggest that this exocentric positioning of the imagery source can produce problems of apparent motion, parallax, and incorrect distance estimation, among other perceptual problems. Of 37 responding exposed subjects, 59% (22) reported that this exocentric viewing condition created problems with obstacle clearance, mostly during taxiing and ground hover (Question 38).

<u>Handedness inventory</u>

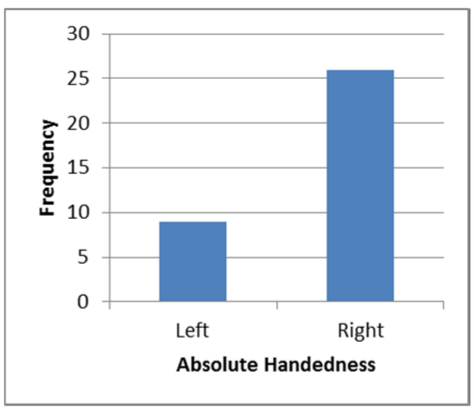
Subject handedness (sometimes referred to as laterality) was assessed using a 10-item self-assessment questionnaire (appendix G) adapted from the EHI by Oldfield (1971). All exposed and control subjects completed the EHI questionnaire at some point in the study. Subjects were asked to indicate their preference in use of hands for various activities, e.g., writing, throwing, using a toothbrush. Both absolute and relative scores were computed for each subject. The absolute score was based on the majority of the 10 responses for the various activities and designated as "Right-" or "Left-" handedness. The EHI relative score was a number between -100 and +100, as calculated by the expression:

[(#R - #L)/(#R + #L)] x 100,

where #L and #R were the total number of left and right hand responses, respectively.[29] A negative score indicates a tendency toward left-handedness; a positive score indicates a tendency toward right-handedness.

The *absolute* handedness scores were predominantly "right" with 86% (56) of 65 responding control subjects indicating a preference for right-handedness and 14% (9) indicating left-handedness. The EHI *relative* scores largely confirmed this finding with an almost equal distribution: 88% (57) indicating right-handedness and 12% (8) indicating left-handedness (figure 13).[30] The *median* EHI relative score was for control subjects was +83, with 28% (18) of respondents indicating an overwhelming preference (+100) for right-handedness. Two (3%) control subjects indicated an overwhelming preference (-100) for left-handedness. The *mean* EHI relative handedness score was +60 (right-handedness).

Exposed subjects' *absolute* handedness scores were predominantly "right" with 81% of the 43 responding subjects, indicating a preference for right-handedness; 19% (8) of exposed subjects indicated left-handedness. The EHI *relative* scores confirmed this finding with the same distribution: 81% indicating right-handedness and 19% indicating left-handedness (figure 14). For exposed subjects, the *median* EHI relative score was +72 (right-handedness), with seven subjects (16%) indicating an overwhelming preference (+100) for right-handedness; no exposed subjects indicated an overwhelming preference (-100) for left-handedness. The *mean* EHI relative handedness score was +50 (right-handedness).



[29] For simplicity, the EHI relative score is expressed as an integer.
[30] One subject who reported a left-handed absolute dominance had an average relative EHI score of 1 (right-handed dominance). This conflict was due to responses on one EHI questionnaire being in contradiction to responses on his other questionnaires.

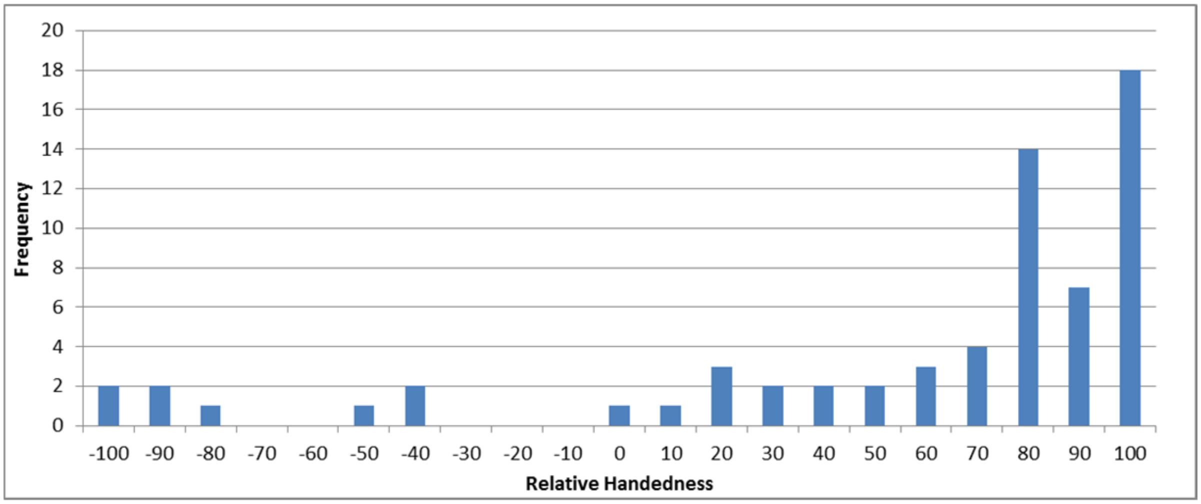
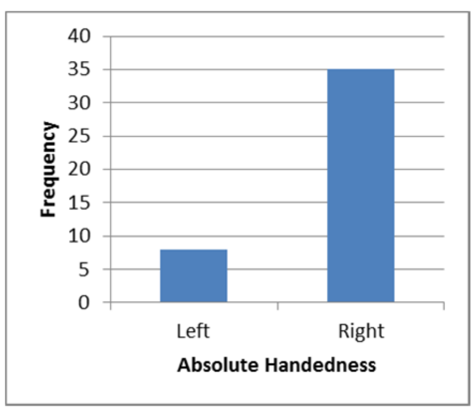


Figure 13. Absolute (top) and relative (bottom) handedness for control subjects.

Both exposed and control subject groups indicated a predominant preference for right-handedness. A two-tailed chi-square test showed no significant difference between the proportions of exposed subjects (R - 81%; L - 19%) and control subjects (R - 86%; L - 14%) ($p = 0.583$).

The difference between the mean relative EHI scores of the two groups (Exposed-50; Control-60) was not statistically significant ($p = 0.398$).

In the general population, the proportion of right-handed people ranges from 90 to 95% (Augustyn and Peters, 1986; Brown and Taylor, 1988). The proportions cited here for the exposed and control groups are slightly lower; this is mostly likely due to the small sample sizes.



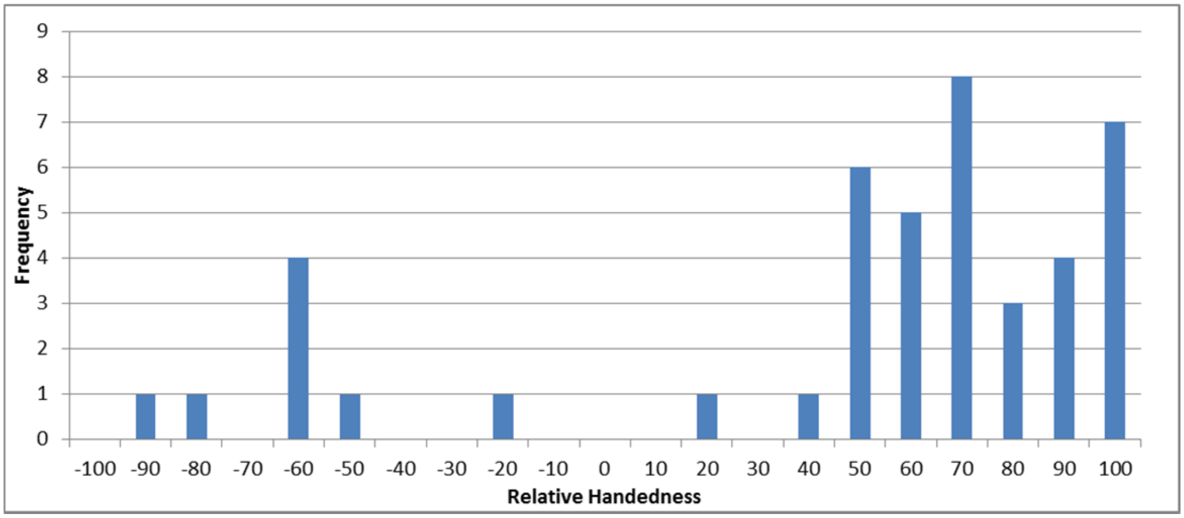


Figure 14. Absolute (top) and relative (bottom) handedness for exposed subjects.

The IHADSS system is monocular in design, providing imagery to the right eye only. It has been suspected that pilots who are left-eye dominant may have increased difficulty learning and using the right-eyed IHADSS (Rash, 2000). While eye dominance only weakly correlates with handedness (Coren, 1993), it was deemed potentially useful to measure handedness. Eye preference was measured during the eye examination for all subjects and the results are reported in the following section.

Eye examination

A series of nine visual tests were administered as an adjunct eye examination component of the regular annual flight physical. Tests of visual performance were conducted monocularly and/or binocularly except where inapplicable (e.g., in eye dominance testing). Visual acuity and contrast sensitivity were measured with the subject's habitual vision correction (spectacles or contact lenses) if the subject presented with correction at the time of the examination.

Over the course of the 10-year study, a total 351 eye exams were conducted: 152 exposed and 199 control. Table 6 and figure 15 provide a summary of the number of eye exams conducted in each year of the study (2001 through 2010).

Table 6.
Number of eye exams conducted by physical year of study (2001 through 2010).

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Exposed	11	23	33	21	25	7	16	4	7	5	152
Control	31	37	42	28	13	4	27	8	5	4	199
Total	42	60	75	49	38	11	43	12	12	9	**351**

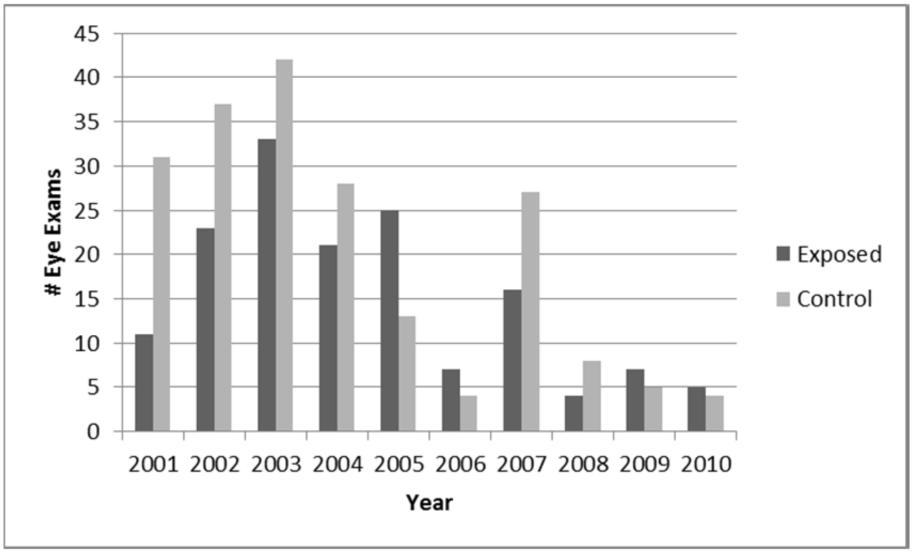


Figure 15. Number of eye exams conducted by physical year of study (2001-2010).

<u>Refractive error</u>

Each subject's refractive error was measured monocularly using an autorefractor (Model AR-600, Nidek Co., LTD., Tokyo, Japan). A single reading was taken for each eye. Each recorded measurement consisted of a sphere, cylinder and axis value. Due to logistical and travel issues associated with remote subject locations, autorefractor data were not available for all exams.

For the 66 control subjects for which two or more refractive data sets were available, the ranges for spherical and cylindrical refractive error (across both eyes) for the initial exams were -2.00 to 3.00 diopters (D) and -1.75D to 0.00D, respectively; for the final exams, the ranges were -2.00D to 4.50D and -1.75D to 0.50D, respectively. The initial exam means for *spherical* refractive error were 0.19D (*SD* = 0.59) and 0.27 (*SD* = 0.77) diopters for the right eye (OD) and left eye (OS), respectively; the final exam means for *spherical* refractive error were 0.21D (*SD* = 0.71) and 0.32D (*SD* = 0.94) diopters for the right eye and left eye, respectively. The initial exam means for *cylindrical* refractive error were -0.51D (*SD* = 0.37) and -0.52D (*SD* = 0.39) for right eye and left eye, respectively; the final exam means for *cylindrical* refractive error were -0.49D (*SD* = 0.44) and -0.50D (*SD* = 0.40) diopters for right eye and left eye, respectively. See table 7.

<u>Table 7.</u>

Summary of initial and final exam refractive error values in diopters.

	Exposed (*n* = 46)	**Control (*n* = 66)**
Spherical refractive error range (across both eyes)	Initial: -2.50 to 1.00 Final: -2.75 to 1.25	Initial: -2.00 to 3.00 Final: -2.00 to 4.50
Cylindrical refractive error range (across both eyes)	Initial: -2.00 to 1.00 Final: -2.00 to 0.50	Initial: -1.75 to 0.00 Final: -1.75 to 0.50
Mean spherical refractive error (Right eye)	Initial: 0.10 Final: 0.04	Initial: 0.19 Final: 0.21

Mean spherical refractive error (Left eye)	Initial: 0.12 Final: 0.08	Initial: 0.27 Final: 0.32
Mean cylindrical refractive error (Right eye)	Initial: -0.44 Final: -0.38	Initial: -0.51 Final: -0.49
Mean cylindrical refractive error (Left eye)	Initial: -0.50 Final: -0.38	Initial: -0.52 Final: -0.50
Mean *spherical equivalent power* (Right eye)	Initial: -0.11 Final: -0.14	Initial: -0.06 Final: -0.03
Mean *spherical equivalent power* (Left eye)	Initial: -0.13 Final: -0.11	Initial: 0.01 Final: 0.06

For the 46 exposed subjects, the ranges for spherical and cylindrical refractive error (across both eyes) for the initial exams were -2.50D to 1.00D and -2.00D to 1.00D, respectively; for the final exams, the ranges were -2.75D to 1.25D and -2.00 to 0.50, respectively. The initial exam means for *spherical* refractive error were 0.10D (*SD* = 0.56) and 0.12D (*SD* = 0.50) for the right eye and left eye, respectively; the final exam means for *spherical* refractive error were 0.04D (*SD* = 0.59) and 0.08D (*SD* = 0.50) for the right eye and left eye, respectively. The initial exam means for *cylindrical* refractive error were -0.44D (*SD* = 0.52) and -0.50D (*SD* = 0.38) for right eye and left eye, respectively; the final exam means for *cylindrical* refractive error were -0.38D (*SD* = 0.50) and -0.38D (*SD* = 0.46) diopters for right eye and left eye, respectively. See table 7.

The *spherical equivalent power* is a standard method for summarizing refractive error into one number and is determined by combining the spherical power with half of the cylindrical power. The initial exam means for *spherical equivalent power* for the 66 control subjects were -0.06D (*SD* = 0.56) and +0.01D (*SD* = 0.72) for right and left eyes, respectively; the final exam means for *spherical equivalent power* for control subjects were -0.03D (*SD* = 0.71) and 0.06D (*SD* = 0.91) for right and left eyes, respectively. The initial exam means for *spherical equivalent power* for the 46 exposed subjects were -0.11D (*SD* = 0.50) and -0.13D (*SD* = 0.55) for right and left eyes, respectively; the final exam means for *spherical equivalent power* for exposed subjects were -0.14D (*SD* = 0.62) and -0.11D (*SD* = 0.55) for right and left eyes, respectively. Box plots of the final exam spherical equivalent refractive error for the right and left eyes for both control and exposed subjects are presented in figure 16.

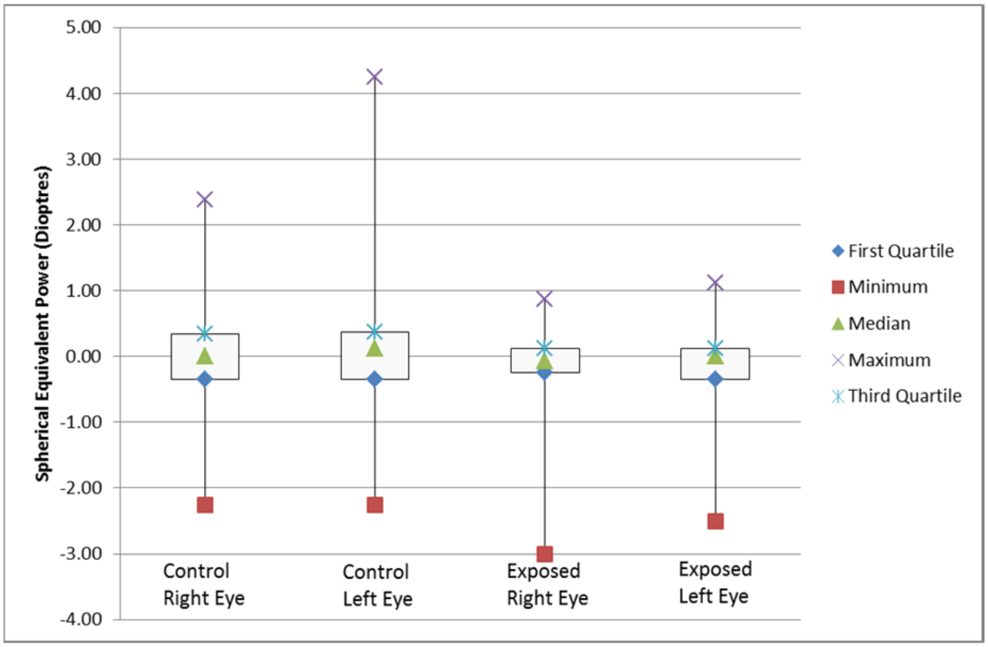


Figure 16. Box plot of spherical equivalent power for the right (OD) and left (OS) eyes for exposed (n = 46) and control (n = 66) subjects.[31]

Aviators tend to have a low level of refractive error as a result of limits set during selection for aviation. In the United Kingdom, for aviators entering flight school, vision unaided in each eye must not be less than 6/12 (20/40), and each eye correctable to 6/6 (20/20). The strength of the required correction cannot exceed -0.75D to +1.75D (spherical) and the astigmatic element must not be greater than +/-0.75D (cylindrical). There is a tendency for refractive error to increase with age, especially in the mid to late twenties, and for individuals to develop presbyopia in their early forties. Both of these factors lead to an increased prevalence of spectacle wear with age, where individuals who did not previously need spectacles develop the need for refractive correction.

The final exam mean *spherical equivalent power* (refractive error) for controls was essentially zero (-0.03D OD; 0.06 OS), clinically equivalent to emmetropia, while the exposed group had a mean spherical equivalent power just slightly in the myopia range (-0.14D OD; -0.11D OS). These differences were not statistically significant (right eyes, p = 0.37; left eyes, p = 0.26). The numerical differences are to the order of 0.1D, a value considered by vision specialists as functionally insignificant.

Bailey-Lovie high contrast visual acuity

The Bailey-Lovie high contrast visual acuity (HCVA) test is designed to measure static visual acuity in a high contrast lighting environment. A chart luminance of approximately 100 candelas per square meter (cd/m^2) was used. Unlike most visual acuity chart, the lines are arranged five letters per line, and the spacing is proportional to ensure equal visual demand near threshold.

[31] The box-length is equivalent to the interquartile range of the data set.

The Bailey-Lovie charts (figure 17) allow the expression of acuity as the logarithm of the minimum resolvable angle (logMAR) and since each letter is scored, the scoring of acuity is more continuous than with the conventional Snellen charts (Bailey and Lovie, 1976). This test was conducted monocularly for both left and right eyes using the habitual correction (either prescribed glasses or no glasses). The test was scored as the total number of letters missed (incorrectly or unidentified letters).

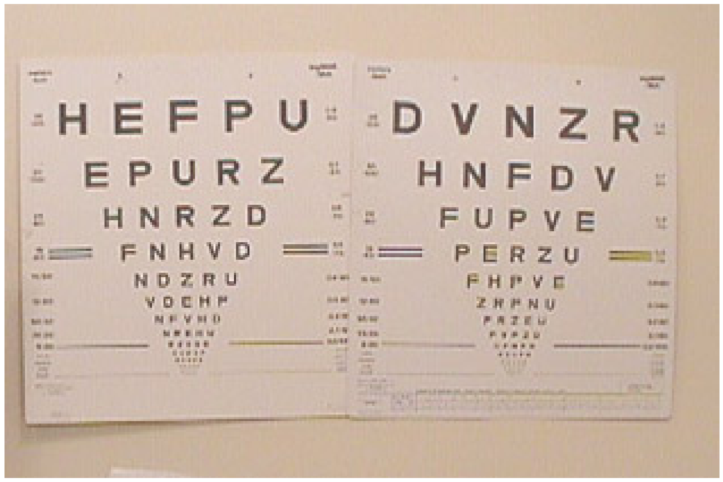


Figure 17. Bailey-Lovie acuity charts.

For clinical interpretation, the mean scores were converted into logMAR using the formula logMAR = -0.3 + N*(0.02) where N is the number of letters missed. Conversion from logMAR to Snellen acuity (20/xx) is accomplished using the Snellen denominator formula:

$$xx = 20 \times 10^{\text{logMAR}}.$$

Bailey-Lovie HCVA values were available for 69 control subjects. For the right eye, the initial mean visual acuity was 0.10 logMAR (Snellen equivalent of 6/7.8 [20/26]) with a standard deviation of 0.09 logMAR; the final right eye mean visual acuity was 0.05 logMAR (Snellen equivalent of 6/6.9 [20/23]) with a standard deviation of 0.11 logMAR. For the left eye, the initial mean visual acuity was 0.11 logMAR (Snellen equivalent of 6/8.1 [20/27]) with a standard deviation of 0.11 logMAR; the final left eye mean visual acuity was 0.06 logMAR (Snellen equivalent of 6/7.2 [20/24]) with a standard deviation of 0.12 logMAR. The control subjects' mean absolute value individual differences between final and initial HCVA values were 0.10 and 0.11 logMAR for the right and left eyes, respectively.[32]

For 43 exposed subjects, for the right eye, the initial mean Bailey-Lovie HCVA was 0.14 logMAR (Snellen equivalent of 6/8.7 [20/29]) with a standard deviation of 0.12 logMAR; the final right eye mean visual acuity was 0.07 logMAR (Snellen equivalent of 6/7.2 [20/24]) with a standard deviation of 0.11 logMAR. For the left eye, the initial mean visual acuity was 0.13 logMAR (Snellen equivalent of 6/8.1 [20/28]) with a standard deviation of 0.11 logMAR; the

[32] Rounding error in statistical calculations and conversions can produce small errors in conversion values for logMAR and Snellen acuity values.

final left eye mean visual acuity was 0.08 logMAR (Snellen equivalent of 6/7.5 [20/25]) with a standard deviation of 0.12 logMAR. The exposed subjects' mean absolute value individual differences between final and initial HCVA values were 0.10 and 0.08 logMAR for the right and left eyes, respectively.

A summary of HCVA values in logMAR, based on the Bailey-Lovie high contrast chart, for the right and left eyes of control and exposed subjects are presented in figure 18.

Visual acuity is an important measure of visual capability of pilots. While visual acuity was expected to be 6/6 (20/20) or better (0.00 logMAR) for this population, the actual final measures were closer to 6/7.2 (20/24 or 0.08 logMAR) for the both control and exposed subjects. This slightly reduced acuity is most likely a consequence of measurements using each pilot's own correction (i.e., contact lenses or eyeglasses), which may or may not been current, or of those subjects reporting for testing without regular correction (although in the worst cases, these data were excluded from the analysis) or low amounts of uncorrected refractive error. There was not a statistically significant difference in the final Bailey-Lovie HCVA for the two groups (right eyes, p = 0.30; left eyes, p = 0.58).

Bailey-Lovie low contrast visual acuity

The Bailey-Lovie low contrast visual acuity (LCVA) test was designed to measure static visual acuity in a low contrast environment, more representative of the real-world aviation environment. The letters on the low contrast side of the chart are 10% (Michelson) contrast. All criteria of the high contrast-test above were applied to this test. This test was conducted monocularly for both right and left eyes. Due to availability of the Bailey-Lovie LCVA chart at the various test locations, these data are missing for some subjects.[33]

Bailey-Lovie LCVA values were available for 49 control subjects. For the right eye, the initial mean visual acuity was 0.37 logMAR (Snellen equivalent of 6/14 [20/49]) with a standard deviation of 0.12 logMAR; the final right eye mean visual acuity was 0.26 logMAR (Snellen equivalent of 6/11.4 [20/38]) with a standard deviation of 0.13 logMAR. For the left eye, the initial mean visual acuity was again 0.37 logMAR (Snellen equivalent of 6/14 [20/49]) with a standard deviation of 0.12 logMAR; the final left eye mean visual acuity was 0.29 logMAR (Snellen equivalent of 6/12 [20/40]) with a standard deviation of 0.11 logMAR. The control subjects' mean absolute value individual differences between final and initial LCVA values were 0.15 and 0.12 logMAR for the right and left eyes, respectively.

For 43 exposed subjects, for the right eye, the initial mean Bailey-Lovie LCVA was 0.40 logMAR (Snellen equivalent of 6/15.6 [20/52]) with a standard deviation of 0.14 logMAR; the final right eye mean visual acuity was 0.30 logMAR (Snellen equivalent of 6/12.6 [20/42]) with a standard deviation of 0.12 logMAR. For the left eye, the initial mean visual acuity was 0.39 logMAR (Snellen equivalent of 6/15.6 [20/52]) with a standard deviation of 0.11 logMAR; the final left eye mean visual acuity was 0.30 logMAR (Snellen equivalent of 6/12.6 [20/42]) with a

[33] The control group was most affected for lack of LCVA data, as control subjects were often examined at remote locations where the Bailey-Lovie LCVA chart was unavailable.

standard deviation of 0.13 logMAR. The exposed subjects' mean absolute value individual differences between final and initial HCVA values were 0.12 and 0.13 logMAR for the right and left eyes, respectively.

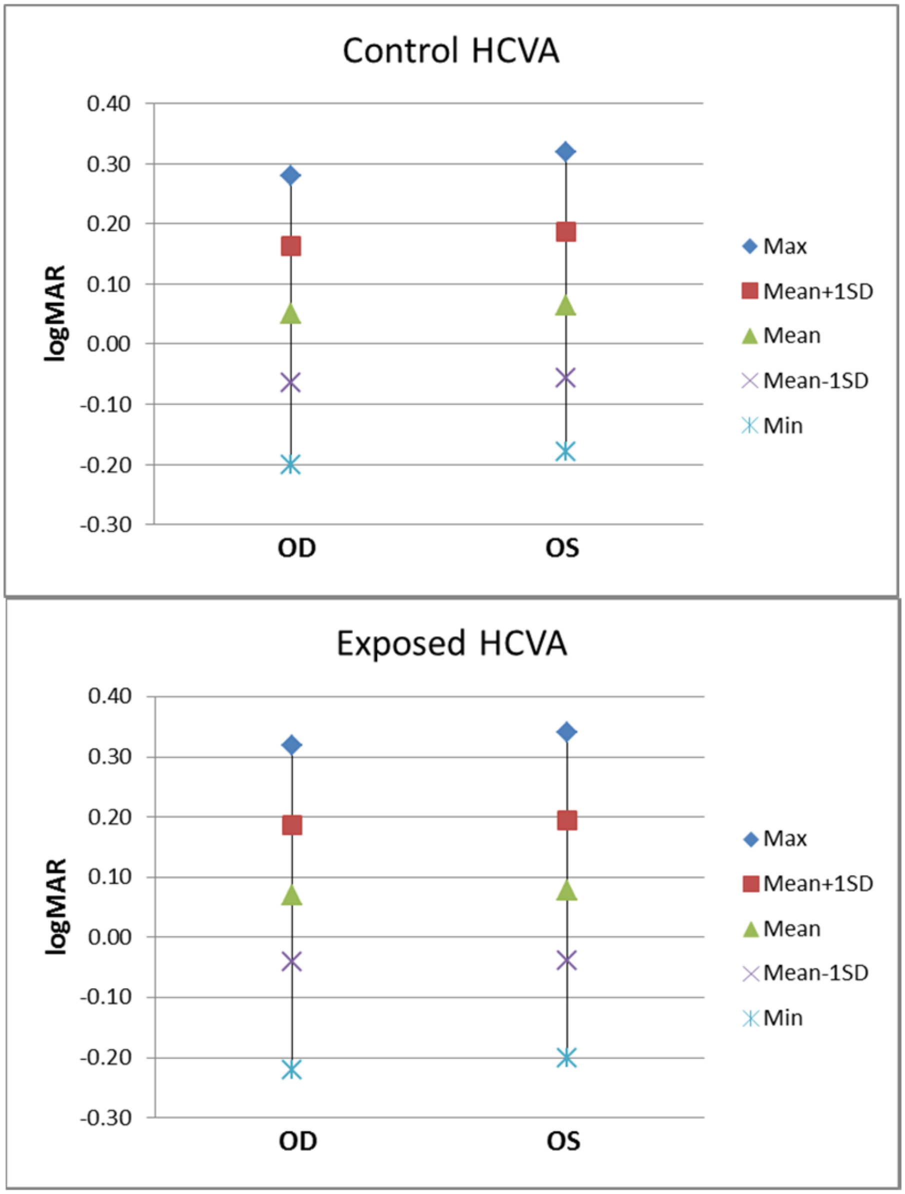


Figure 18. Summary of Bailey-Lovie HCVA, expressed in logMAR, for right (OD) and left (OS) eyes for control (top) (n = 69) and exposed (bottom) (n = 43) subjects.

The ability to see low contrast letters is affected by the optics of the eye, uncorrected refractive error, and/or the sensitivity of the retina. Optics of the eye include clarity of the media, specifically the cornea and lens, and pupil size; both tend to decrease with age. The mean age difference between the two groups was very small at 3 years, and the two groups were still relatively young, and changes are generally not evident until the fifth or sixth decade of life.

There was not a statistically significant difference in the LCVA of the two groups for either right or left eyes (right eyes, p = 0.13; left eyes, p = 0.68).

A summary of 10% LCVA values in terms of logMAR for the right and left eyes of control and exposed subjects are presented in figure 19.

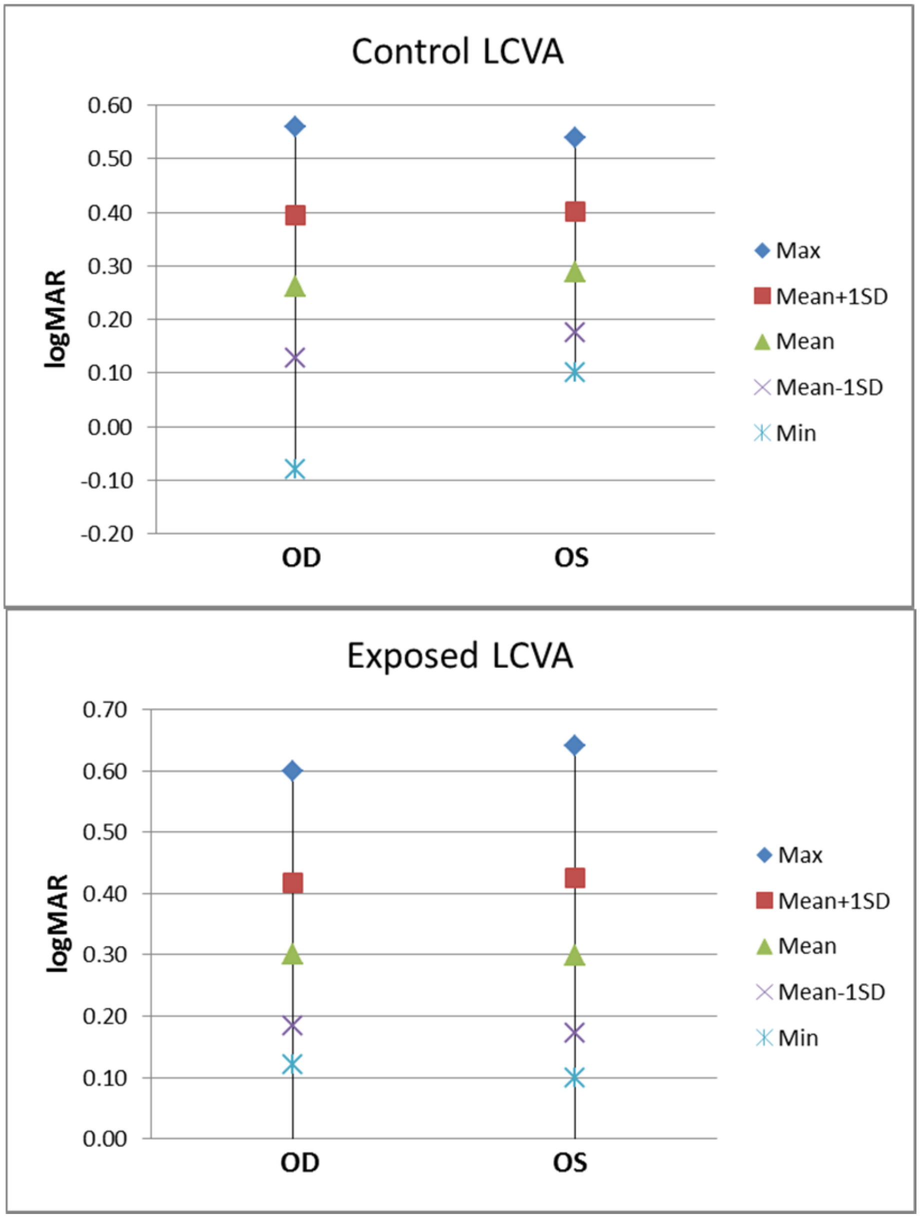


Figure 19. Summary of Bailey-Lovie LCVA, expressed in logMAR, for right (OD) and left (OS) eyes for control (top) (n = 49) and exposed (bottom) (n = 43) subjects.

Small letter contrast sensitivity

The SLCT used a chart developed at USAARL (figure 20) that presents rows of letters of one size decreasing in contrast level by 0.1 log for each row on the chart. It is a measure of small letter contrast sensitivity (CS) and has been shown to be sensitive to slight changes in visual performance (Rabin and Wicks, 1996). The subject was asked to read down the chart's left side, giving the first letter of each row. When the subject appeared to hesitate at a specific row, that row was used as the threshold for beginning the test.

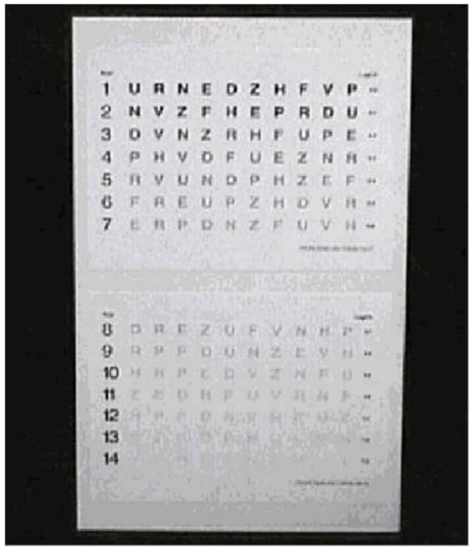


Figure 20. Test chart for small letter contrast sensitivity.

The subject then was asked to begin reading the preceding entire row of letters, continuing as far down the chart as possible. This test was conducted monocularly for both left and right eyes using habitual correction. The measured data value is the total number of incorrect (unreadable) letters. Each score is converted into a meaningful value of logCS using the formula:

$$\text{logCS} = 1.3 - N*(0.01),$$

where N is the total number of missed letters.

The *mean expected score* on this test is logCS = 1.1. Scores below 0.8 are considered below normal (Rabin, 2003; van de Pol, 2003).

SLCT data values were taken for 63 control subjects. A summary of SLCT in terms of logCS for the right and left eyes of control and exposed subjects are presented in figure 21. For the right eye, the mean final contrast sensitivity was 1.05 logCS (*SD* = 0.21); the final left eye mean was 1.07 logCS (*SD* = 0.16). For exposed subjects (*n* = 43), the final right eye mean contrast sensitivity was 1.02 logCS (*SD* = 0.24). For the left eye, the final *M* was 1.04 logCS (*SD* = 0.21).

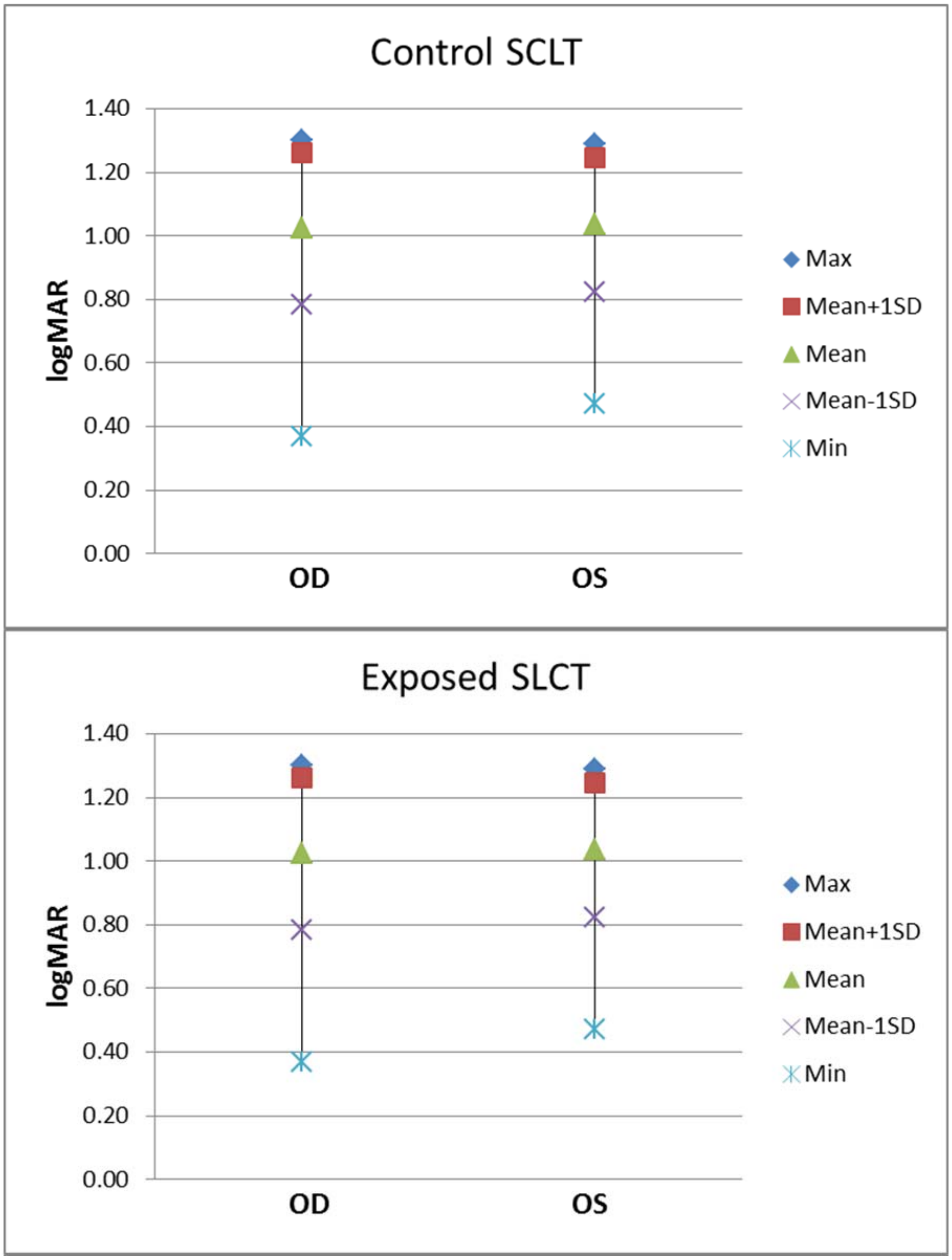


Figure 21. SLCT scores expressed in logCS, for right (OD) and left (OS) eyes for control (top) (n = 63) and exposed (bottom) (n = 43) subjects.

There was not a statistically significant difference between groups for final SLCT scores (right eyes, $p = 0.39$; left eyes, $p = 0.68$).

Depth perception

Depth perception (stereopsis) was measured using the Stereotest-Circles test (Stereo Optical Co., Inc., Chicago, Illinois) (figure 22). Wearing polarized glasses, subjects viewed

arrangements of three circles and determined which circle in each group of three appeared closest. The recorded data point was the angular measure of the last correct answer, expressed in seconds of arc (arcsec). The test was performed binocularly.

Figure 22. The Stereotest-Circles depth perception test.

Depth perception values for all subjects, exposed (*n* = 45) and control (*n* = 70), are summarized in table 8. Initial control subject scores ranged from 20 to 50 arcsec with a *M* and *Mdn* of 26.4 (*SD* = 4.2) and 25 arcsec, respectively; final scores ranged from 20 to 70 arcsec with a *M* and *Mdn* of 28.4 (*SD* = 12.1) and 25 arcsec, respectively. The mean difference between initial and final scores for control subjects was 2.0 arcsec.

For exposed subjects, initial scores ranged from 20 to 30 arcsec with a *M* and *Mdn* of 25.9 (*SD* = 2.7) and 25.0 arcsec, respectively; final scores ranged from 20 to 70 arcsec with a *M* and *Mdn* of 28.6 (*SD* = 12.2) and 25.0 arcsec, respectively. The mean difference between initial and final scores for exposed subjects was 2.7 arcsec.

Table 8.
Summary of depth perception data.

	Initial scores (arcsec)			**Final scores (arcsec)**			**Difference**
	Range	*M*	*Mdn*	Range	*M*	*Mdn*	*M*
Control (*n* = 70)	20-50	26.4	25	20-70	28.4	25	2.0
Exposed (*n* = 45)	20-30	25.9	25	20-70	28.6	25	2.7

The mean depth perception scores for the control and exposed groups represent excellent depth perception; 120 seconds of arc or better is the standard for British Army aviators. Four control and two exposed subjects performed worse than this standard, on average, over the course of the study. There was no statistically significant difference between the groups for final scores
(p = 0.93) or for differences between final and initial scores (p = 0.78).

Color perception

The Lanthony desaturated D-15 hue test (figure 23), adapted from the Farnsworth (1947) Panel D-15 test, was used to measure color vision. This test consists of 16 color chips/tabs selected from the Munsell (1929) book of color that are desaturated and appear pale and light. The subject's task is to arrange the color chips in order according to color starting with the base/fixed cap. In order to compare small differences in performance, a modified Farnsworth-Munsell (1943) FM-100 test quantitative perception scoring scheme was used. When all caps are correct, the color perception score is 0. Errors in the cap sequencing result in an increase in score. The Panel D-15 total error score (TES) was calculated using the calculation proposed by Lanthony (1986). This test was conducted monocularly for both left and right eyes. Scoring was performed using a web-based computer program designed for analyzing the Lanthony desaturated D-15 hue test (Torok, 2011).

A second metric that was calculated from the D-15 test is the CCI, a measure of the severity of the color deficit. Perfect color vision has a CCI of 1, whereas color blind individuals will score between 1 and 4 (sometimes higher). The higher the CCI, the more severe the color blindness.

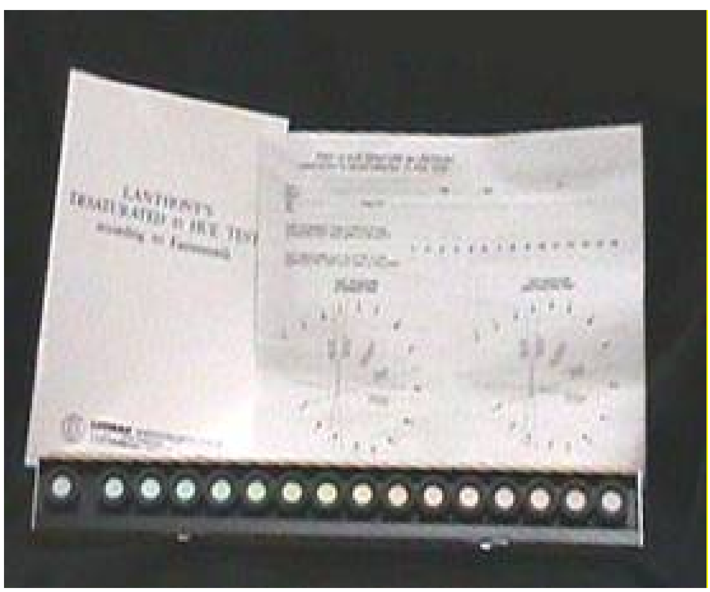


Figure 23. The Lanthony (1986) desaturated D-15 hue test.

For 70 control subjects, the mean final TES and CCI scores for the right eye were 4.2 (*SD* = 6.28) and 1.1 (*SD* = 0.18), respectively. For the left eye, the mean final TES and CCI scores

were 4.2 (*SD* = 7.16) and 1.1 (*SD* = 0.25), respectively. Differences in both TES and CCI scores were calculated based on initial and final scores. Mean TES and CCI differences for the right eye were -1.77 (*SD* = 7.12) and -0.05 (*SD* = 0.20), respectively. For the left eye, mean final TES and CCI differences were -0.56 (*SD* = 9.40) and -0.02 (*SD* = 0.26), respectively. For these difference statistics, a negative value implies an improvement (however small) in color perception.

For 46 exposed subjects, the mean final TES and CCI scores for the right eye were 6.83 (*SD* = 9.91) and 1.18 (*SD* = 0.36), respectively. For the left eye, the mean final TES and CCI scores were 4.80 (*SD* = 7.54) and 1.13 (*SD* = 0.30), respectively. Differences in both TES and CCI scores were calculated based on initial and final scores. Mean TES and CCI differences for the right eye were 0.67 (*SD* = 9.32) and 0.00 (*SD* = 0.32), respectively. For the left eye, mean final TES and CCI differences were -1.59 (*SD* = 7.07) and -0.07 (*SD* = 0.28), respectively.

Color perception performance is summarized in table 9.

Table 9.
Summary of color perception data.

	Control (n = 70)	**Exposed (n = 46)**	**Comparison**
Total Error Score (TES) difference			
Right eye (*M*)	-1.77	0.67	p = 0.13
Left eye (*M*)	-0.56	-1.59	p = 0.50
Color Confusion Index (CCI) difference			
Right eye (*M*)	-0.05	0.00	p = 0.40
Left eye (*M*)	-0.02	-0.07	p = 0.36

Note: Negative scores denote improvement in color performance.

The differences in TES and CCI scores for both groups were extremely small. There was not a statistically significant difference between the groups for either the TES differences (right eyes, p = 0.13; left eyes, p = 0.50) or CCI differences (right eyes, p = 0.40; left eyes, p = 0.36).

Accommodation

In a standard aircrew medical examination, accommodation is measured in a binocular fashion, stimulating convergence and accommodation together by maintaining focus and fusion on a target. In this study, accommodation without spectacle correction was tested binocularly and monocularly by moving a small-print target on a Prince Rule (figure 24) slowly away from each eye in turn, noting when the subject can read the letters on the target. The values recorded were the measured distances, expressed in centimeters (cm). These values were converted into diopter values (the inverse of the focusing distance in meters).

Figure 24. Accommodation rule test.

Accommodation data were available for 67 control subjects. The results are presented based on age at *last* exam date (in decade groups).[34] The *M* and *Mdn* ages across all control subjects were 35.2 and 32 years, respectively. By decade, 14 subjects were 26 to 29 years of age (*Mdn* = 27 years); 38 subjects were 30 to 39 years of age (*Mdn* = 35 years); 9 subjects were 40 to 47 years of age (*Mdn* = 42 years); and 6 subjects were 50 to 55 (*Mdn* = 51.5 years).

Accommodation data were available for 46 exposed subjects. The *M* and *Mdn* ages across all control subjects were 38.1 and 38 years, respectively. By decade, 3 subjects were 28 to 29 years of age (*Mdn* = 28); 24 subjects were 30 to 39 years of age (*Mdn* = 35 years); 17 subjects were 40 to 48 years of age (*Mdn* = 42 years); and 2 subjects were 52 to 54 (*Mdn* = 53 years).

Three approaches using binocular data were used to investigate potential between-subject differences in binocular accommodation. In the first approach, final accommodation values were compared. The second approach compared differences between final and initial accommodation values. The final approach compared rates of accommodative change, expressed in diopters per year of study participation. Final, difference and rate of change accommodation values are summarized by decade in table 10.

Final accommodation values

The *M* final exam *binocular* accommodation for control subjects was 7.5D (*SD* = 1.2) for the youngest decade group, 6.7D (*SD* = 1.6) for the 30 to 39 year group, 4.4D (*SD* = 0.9) for the 40 to 49 year group, and 3.2D (*SD* = 0.6) for the oldest decade

[34] The amplitude of accommodation declines with age. By the fifth decade of life, the accommodative amplitude has declined so the near point of the eye is more remote than the reading distance (Borish, 1954).

Table 10.
Summary of binocular accommodation data.

Decade range	Control (n = 67)	Exposed (n = 46)	Comparison
20 to 29 years	***n* = 14**	***n* = 3**	
M final	7.5 D	9.1 D	***p* = 0.04**
M difference	-1.0 D	0.2 D	*p* = 0.22
M rate of change (D/Year)	0.1	0.0	*p* = 0.79
30 to 39 years	***n* = 38**	***n* = 24**	
M final	6.7 D	6.2 D	*p* = 0.22
M difference	-0.6 D	-1.1 D	*p* = 0.25
M rate of change (D/year)	-0.2	-0.4	*p* = 0.27
40 to 49 years	***n* = 9**	***n* = 17**	
M final	4.4 D	4.4 D	*p* = 0.93
M difference	-1.8 D	-2.6 D	*p* = 0.31
M rate of change (D/year)	-0.3	-0.7	*p* = 0.17
50 to 59 years	***n* = 6**	***n* = 2**	
M final	3.2 D	3.4 D	*p* = 0.85
M difference	0.3 D	-0.8 D	*p* = 0.11
M rate of change (D/year)	0.1	-0.1	***p* = 0.01**

Note: **Bold *p*-value** implies a statistically significant difference.

group. *Monocularly*, the *M* accommodation for the 20 to 29 year control group was 7.6D (*SD* = 1.0) for the right eye and 7.5D (*SD* = 1.0) for the left eye; the *M* accommodation for the 30 to 39 year group was 6.5D (*SD* = 1.6) for the right eye and 6.5D (*SD* = 1.7) for the left eye; the *M* accommodation for the 40 to 49 year group was 4.1D (*SD* = 0.8) for the right eye and 3.9D (*SD* = 1.0) for the left eye; the *M* accommodation for the 50 to 59 year group was 3.1D (*SD* = 0.7) for both the right and left eye.

Mean final *binocular* accommodation for exposed subjects was 9.1D (*SD* = 0.8) for the youngest decade group, 6.2D (*SD* = 1.5) for the 30 to 39 year group, 4.4D (*SD* = 1.5) for the 40 to 49 year group, and 3.4D (*SD* = 1.3) for the oldest decade group. *Monocularly*, the *M* accommodation for the 20 to 29 year control group was 8.6D (*SD* = 1.7) for the right eye and 8.4D (*SD* = 2.0) for the left eye; the *M* accommodation for the 30 to 39 year group was 5.9D (*SD* = 1.5) for the right eye and 69.3D (*SD* = 1.4) for the left eye; the *M* accommodation for the 40 to 49 year group was 4.2D (*SD* = 1.4) for the right eye and 4.3D (*SD* = 1.5) for the left eye; the *M* accommodation for the 50 to 59 year group was 2.8D (*SD* = 0.9) for the right eye and 2.7D (*SD* = 0.3) for the left eye.

Final *binocular* accommodation values (in diopters) by age decade for all subjects are summarized in table 10. Compared using 2-tailed, 0.05-level *t*-tests, only the 20 to 29 year decade final values were found to be significantly different (p = 0.04); however, only three exposed subjects were present in the comparison.

Accommodation difference

While final accommodation values are useful, it is more meaningful to investigate the change or difference in accommodative power for each subject. Therefore, a difference value, defined as final minus initial exam values were calculated for each subject. Mean *binocular* accommodation difference for control subjects was -1.0D (*SD* = 2.4) for the youngest decade group, -0.6D (*SD* = 1.0) for the 30 to 39 year group, -1.8D (*SD* = 0.8) for the 40 to 49 year group, and 0.3D (*SD* = 0.5) for the oldest decade group. *Monocularly*, the *M* accommodation for the 20 to 29 year control group was -0.7D (*SD* = 2.2) for the right eye and -1.0D (*SD* = 2.1) for the left eye; the *M* accommodation for the 30 to 39 year group was -0.8D (*SD* = 1.4) for the right eye and -0.8D (*SD* = 1.1) for the left eye; the *M* accommodation for the 40 to 49 year group was -2.2D (*SD* = 0.8) for the right eye and -2.3D (*SD* = 0.8) for the left eye; the *M* accommodation for the 50 to 59 year group was -0.2D (*SD* = 1.0) for the right eye and 0.6D (*SD* = 0.5) for the left eye.

Mean *binocular* accommodation for exposed subjects was 0.2D (*SD* = 2.4) for the youngest decade group, -1.1D (*SD* = 1.5) for the 30 to 39 year group, -2.6D (*SD* = 3.0) for the 40 to 49 year group, and 0.8D (*SD* = 0.5) for the oldest decade group. *Monocularly*, the *M* accommodation for the 20 to 29 year control group was -0.2D (*SD* = 1.1) for the right eye and -0.1D (*SD* = 1.7) for the left eye; the *M* accommodation for the 30 to 39 year group was -1.3D (*SD* = 2.0) for the right eye and -1.0D (*SD* = 1.6) for the left eye; the *M* accommodation for the 40 to 49 year group was -2.7D (*SD* = 3.4) for the right eye and -2.9D (*SD* = 3.4) for the left eye; the *M* accommodation for the 50 to 59 year group was -1.7D (*SD* = 1.1) for the right eye and -1.4D (*SD* = 1.1) for the left eye.

Binocular accommodation difference values (in diopters) by age decade for all subjects are summarized in table 10. Compared using 2-tailed, 0.05-level *t*-tests, none of the decades were found to be significantly different.

Rate of accommodative change

A third analysis of accommodation data involved calculating the rate of change of accommodative power. This rate was defined as the subject's accommodation difference divided by the number of years each subject participated in the study and was expressed as diopters per year.

Mean *binocular* rates of accommodative change for control subjects was -0.1D per year (*SD* = 1.6) for the youngest decade group, -0.2D per year (*SD* = 0.3) for the 30 to 39 year group, -0.3D per year (*SD* = 0.2) for the 40 to 49 year group, and 0.1D per year (*SD* = 0.1) for the oldest decade group.

Mean *binocular* rates of accommodative change for exposed subjects was 0.0 diopter per year (*SD* = 0.3) for the youngest decade group, -0.4D per year (*SD* = 0.5) for the 30 to 39 year group, -0.7D per year (*SD* = 1.0) for the 40 to 49 year group, and -0.1D per year (*SD* = 0.0) for the oldest decade group.

Binocular rates of accommodative change by age decade for all subjects are summarized in table 10. Compared using 2-tailed, 0.05-level *t*-tests, only the 50 to 59 year decade rate values were found to be significantly different ($p = 0.01$); however, only two control subjects were present in the comparison.

Eye muscle balance

The eyes are held in place by three pairs of muscles that constantly balance the pull of the others. These muscles work together to move the eyes in unison, which allow the eyes to track moving objects. Binocular vision is a consequence of the separation of the eyes, which results in two views of the scene. To prevent double vision (diplopia), the eye uses a movement called *vergence*. The eyes turn to direct the images directly onto the retina. The brain fuses these two images into one.

When both eyes fail to point to the same location in space, a condition known as heterotropia or strabismus exist. The condition is diagnosed using the unilateral cover test; the subject fixates on a point in space and one eye is covered. If the uncovered eye refixates to the point, this indicates the eye was not aligned. In cases of strabismus, individuals will see double or suppress the image of one eye; in either adaptation stereopsis will not exist. Both eyes are checked using the unilateral cover test. If neither eye refixates when the opposite eye is covered, strabismus is not present and the subject is considered orthotropic.

Covering one of the eyes and noting the change in the line of sight of the covered eye can test eye muscle balance. If both eyes accurately point toward the target when each eye is covered separately, this normal muscle condition is called *orthophoria* (figure 25). If the line of sight departs from the target object, a condition known as *heterophoria* exists. Such departure can be either lateral or vertical in nature. If the line of sight of the covered eye laterally departs such as to turn outward, a condition called exophoria is present; if the line of sight of the covered eye laterally departs such as to turn inward a condition called *esophoria* is present (figure 25). If the line of sight of either covered eye vertically departs from normal vergence, such that one line of sight is directed above the plane of the other, a condition called *hyperphoria* is present (figure 26) (Borish, 1949).

In the two-year review report (Rash et al., 2004), a recommendation was made to replace the then-used Maddox rod test to measure muscle balance with some form of automated testing. This recommendation was based on the complexity and difficulty associated in the administration of this test by non-optometric medical personnel. As a result, in 2002, the Maddox rod device was replaced with the Optec® 2000 Vision Tester (figure 27).

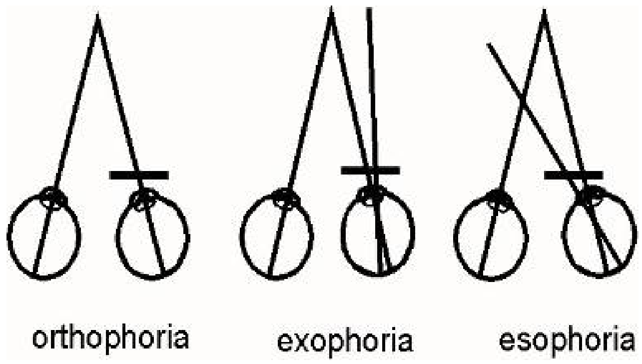


Figure 25. Diagram of orthophoria and lateral heterophorias (adapted from http://spectacle.berkeley.edu/cleere/glossaryNZ.html).

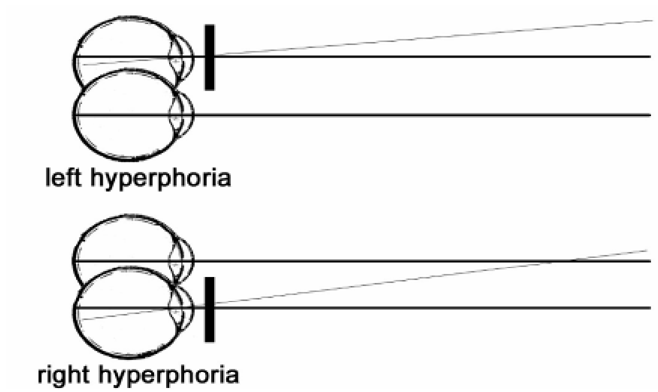


Figure 26. Diagram of hyperphorias.

Figure 27. Eye muscle balance test equipment (Optec® 2000 Vision Tester).

Eye muscle balance was measured for both *far* (6 m [20 ft]) and *near* (~½ m [18 in]) distance conditions. Eye muscle balance scores were recorded as integers (1 to 9 for vertical phoria; 1 to

30 for lateral phoria) and are converted into the corresponding condition (e.g., hyperphoria, esophoria, exophoria) and prism diopter value using conversion tables (table 11). If orthophoria was determined, it was so noted. If heterophoria was present, the extent of the esophoria, exophoria or hyperphoria was recorded in prism diopters.

Table 11.
Scoring conversion tables for *far* and *near* Optec® 2000 Vision Tester
eye muscle balance scores.

Far									
Score	1	2	3	4	5	6	7	8	9
Prism diopters	2.0	1.5	1.0	0.50	0	0.5	1.0	1.5	2.0
	Left *hyperphoria*					Right *hyperphoria*			
	Score minus 11 = Prism diopters of *exophoria* 11 minus score = Prism diopters of *esophoria*								
Near									
Score	1	2	3	4	5	6	7	8	9
Prism diopters	2.0	1.5	1.0	0.50	0	0.5	1.0	1.5	2.0
	Left *hyperphoria*					Right *hyperphoria*			
	Score minus 13 = Prism diopters of *exophoria* 13 minus score = Prism diopters of *esophoria*								

The final exam muscle balance scores for both control and exposed groups are summarized in table 12 and figures 28 and 29.

Eye balance data were available for 66 control subjects. Two subjects were measured having orthophoria at *far* distance; three were orthophoric at *near* distance. All other control subjects had a measurable heterophoria at *far* and *near* distances. For *far* distance, 57 (86%) were esophoric, 5 (8%) were exophoric, and 41 (62%) were hyperphoric. Esophoria ranged from 1 to 8 prism diopters; exophoria ranged from 1 to 3 prism diopters; and hyperphoria ranged from was 0.5 to 1 prism diopters, right and left.

For *near* distance control subjects, 50 (76%) were esophoric, 11 (16%) were exophoric and 48 (73%) were hyperphoric. Esophoria ranged from 1 to 12 prism diopters; exophoria ranged from 1 to 2 prism diopters; and hyperphoria ranged from 0.5 to 1.5 prism diopters, right and left.

Eye muscle balance was measured for all 46 exposed subjects. One subject each was measured to have orthophoria at *far* or *near* distance. All other subjects had a measurable heterophoria at *far* distance; 39 (85%) were esophoric, 3 (7%) were exophoric, and 28 (61%) were hyperphoric (22 right and 6 left). Esophoria ranged from 1 to 9 prism diopters (M = 2.6 prism diopters); exophoria ranged from 1 to 3 prism diopters (M = 2.3 prism diopters); and hyperphoria ranged from was 0.5 to 1 prism diopters right and 0.5 to 1.5 prism diopters left.

Table 12.

Summary of *far* and *near* eye muscle balance scores.[35]

Control (*n* = 66) Far distance					
	Vertical		Lateral		
	No phoria	Hyperphoria	No phoria	Esophoria	Exophoria
Frequency	25 (38%)	41 (62%)	4 (6%)	57 (86%)	5 (8%)
Minimum		Right 6 (0.5D) Left 3 (1.0D)		3 (8D)	12 (1D)
Maximum		Right 7 (1.0D) Left 4 (0.5D)		10 (1D)	14 (3D)
M	5 (0D)	Right 6.2 (0.6D) Left 3.7 (0.65D)	11 (0D)	8.3 (2.7D)	12.8 (1.8D)
Control (*n* = 66) Near distance					
	Vertical		Lateral		
	No phoria	Hyperphoria	No phoria	Esophoria	Exophoria
Frequency	18 (27%)	48 (73%)	5 (8%)	50 (76%)	11 (16%)
Minimum		Right 6 (0.5D) Left 2 (1.5D)		1 (12D)	14 (1D)
Maximum		Right 8 (1.5D) Left 4 (0.5D)		12 (1D)	15 (2D)
M	5 (0D)	Right 7.0 (1.0D) Left 3.4 (0.8D)	13 (0D)	7.8 (5.2D)	14.5 (1.5D)
Exposed (*n* = 46) Far distance					
	Vertical		Lateral		
	No phoria	Hyperphoria	No phoria	Esophoria	Exophoria
Frequency	18 (29%)	28 (61%)	4 (9%)	39 (85%)	3 (7%)
Minimum		Right 6 (0.5D) Left 2 (1.5D)		2 (9D)	12 (1D)
Maximum		Right 7 (1.0D) Left 4 (0.5D)		10 (1D)	15 (4D)
M	5 (0D)	Right 6.2 (0.6D) Left 3.0 (1.0D)	11 (0D)	8.4 (2.6D)	13.3 (2.3D)
Exposed (*n* = 46) Near distance					
	Vertical		Lateral		
	No phoria	Hyperphoria	No phoria	Esophoria	Exophoria
Frequency	17 (37%)	29 (63%)	2 (4%)	39 (85%)	5 (11%)
Minimum		Right 6 (0.5D) Left 1 (2.0D)		2 (11D)	14 (1D)
Maximum		Right 7 (1.0D) Left 4 (0.5D)		12 (1D)	15 (2D)
M	5 (0D)	Right 6.3 (0.65D) Left 3.5 (0.75D)	13 (0D)	8 (5D)	14.6 (1.6D)

[35] Lateral phoria cores for *far* and *near* distances do not have a one-to-one correspondence.

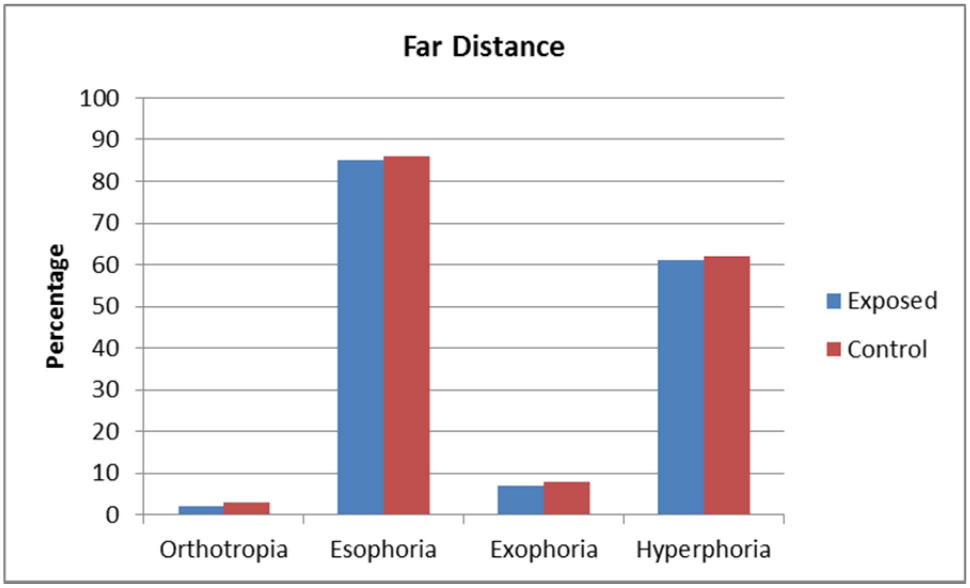


Figure 28. Eye muscle balance for *far* condition.

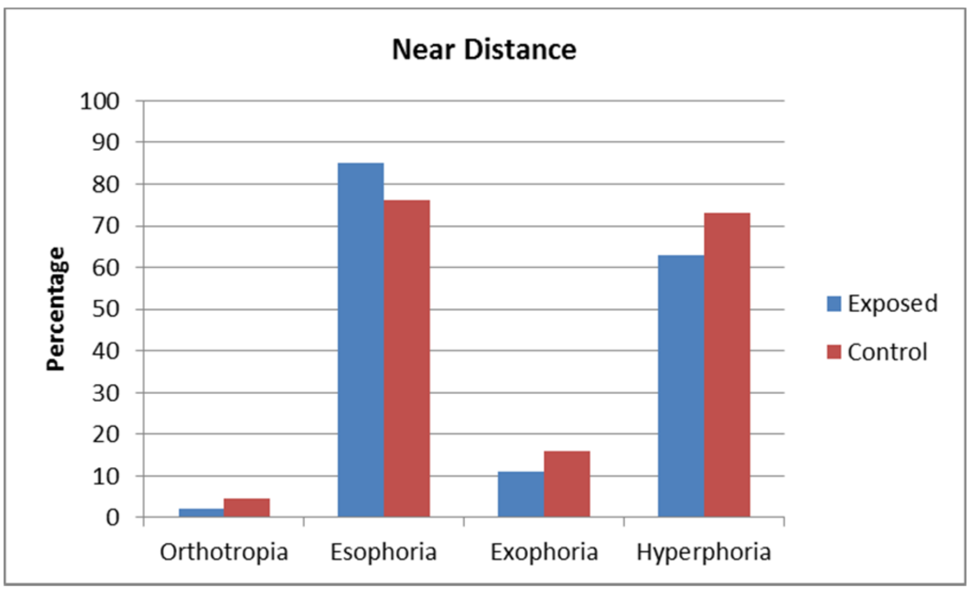


Figure 29. Eye muscle balance for *near* distance.

All 46 exposed subjects had a measurable heterophoria at *near* distance; 39 (85%) were esophoric, 5 (11%) were exophoric, and 29 (63%) were hyperphoric (4 right and 25 left). Esophoria ranged from 1 to 11 prism diopters (*M* = 5.0 prism diopters); exophoria ranged from 1 to 2 prism diopters (*M* = 1.6 prism diopters); and hyperphoria ranged from was 0.5 to 1 prism diopters right and 0.5 to 2 prism diopters left.

Heterophoria is a measure of the solidness of ocular alignment and binocular fusion to a target at a given distance. For both groups, esophoria was the most common condition for both far and

near targets. The *far* and *near* distributions of heterophorias were very similar for both groups and was not statistically different between groups (*far*, p = 0.99; *near*, p = 0.54).[36]

<u>Eye dominance</u>

As a measure of eye dominance, a sighting test was used. The selected test is called the "hole" test, in which the subject views the examiner's head through a hole in a card, and then closes each eye alternately allowing the examiner to determine which eye was being used by the subject for sighting. The test was conducted under normal room lighting with the subject and examiner approximately 3 m (10 ft) apart. At each annual exam, the test was repeated four times, and the predominant eye was recorded.

Sixty-nine percent (48) of the 70 control subjects were measured to have "right" eye dominance; 17% (12) were measured to have "left" eye dominance; and 14% (10) failed to show dominance in neither eye.[37] Seventy-four percent (34) of the 46 exposed subjects were measured to have "right" eye dominance; 15% (7) were measured to have "left" eye dominance; and 11% (5) failed to show dominance in neither eye. The distribution of results for the eye dominance test for control and exposed subjects is presented in figure 30.

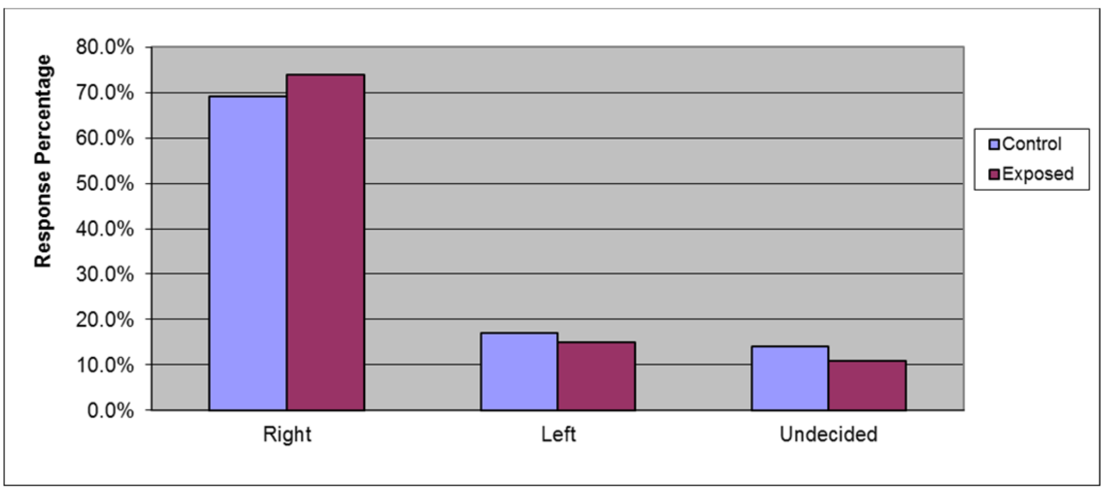


Figure 30. Eye dominance distribution for control (n = 70) and exposed (n = 46) subjects.

Both groups demonstrated similar distributions for the "hole" dominance test, with larger proportions for "right" eye dominance. A chi-square analysis found no significant difference between these proportion distribution (p = 0.807).

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[36] Chi-square tests and Freeman-Halton extension of Fisher exact probability tests for the eye muscle 2 x 4 contingency tables failed to meet the necessary expected cell frequency and total frequency (*N*) values criteria; therefore, reported *p*-values are based on 2 x 3 contingency tables excluding orthophoria frequencies.

[37] For the majority of both control and exposed subjects, eye dominance measurements were in agreement for all tests. However, if a subject's dominance measurement was inconsistent, specific *right* or *left* eye dominance was designated when the ratio of one dominance type to the other equaled or exceeded 2:1. If this ratio criteria was not met, the subject was designated as having *neither* eye dominant, i.e., undecided.

In general, the right-eye trend in the proportions for both control and exposed subjects agrees with the eye preference question in the vision history section (Question 17) of the annual questionnaires. However, for both groups, the proportion for subjects reporting no preferred eye was lower that the proportion actually measured as showing neither eye as dominant by the dominance test. This is not a surprising finding, as the dominant eye and the perception of ocular dominance can switch depending on viewing distance or visual task (Crider, 1944; Salmon, van de Pol and Rash, 2009). During the first years of fielding the Apache, the training failure rate was high (~10%), and eye dominance was suggested as a probable cause. McLean (1990) correlated data on 16 U.S. Army Apache aviators for multiple eye dominance tests. Results showed little correlation between tests. This was explained by the rationale that eye dominance itself is not a singularly defined concept and is task dependent. Also, data failed to show any before and after effects on eye dominance due to PNVS training

Only one exposed subject showed any verifiable change in measured eye dominance over the course of the study. This subject was measured to have right eye dominance during the first 3 consecutive exams, followed by three consecutive exams of left eye dominance measurements.

Within-subject analyses (Exposed)

An obligatory objective of this study is to ensure that no evidence exists indicating that exposed subjects (i.e., Apache pilots) are being harmed (i.e., reduction in visual function) by the use of the monocular IHADSS HMD. These expanded analyses were conducted even though between-subject analyses showed no differences in performance between exposed and control subjects. Most of the following analyses employed paired-samples *t*-tests[38] using final vision test scores for the right and left eyes.

Refractive error

A paired-samples *t*-test was conducted to evaluate whether there was a significant difference in spherical equivalent refractive error scores between the final measurements for the right and left eyes for exposed subjects (n = 46). The results indicated that the M for the measurement for the right eye (M = -0.14D, SD = 0.61) was not statistically significantly different from the M for the left eye (M = -0.11D, SD = 0.55), with p = 0.364.

Bailey-Lovie high contrast visual acuity

For clinical interpretation, logMAR scores were determined using the formula logMAR = -0.3 + N*(0.02) where N is the number of letters missed (one letter corresponds to a logMAR difference of 0.02). Conversion from logMAR to Snellen acuity is accomplished using the formula to determine the Snellen denominator: $(20/xx) = 20 \times 10^{\text{logMAR}}$. Note that the higher (or more plus) the logMAR value, the lower the performance.

[38] The paired samples *t*-test is used to test the null hypothesis that the average of the differences between a series of paired observations (e.g., right vs. left eye) is zero.

A 2-tailed paired-samples *t*-test was conducted to evaluate whether there was a significant difference in Bailey-Lovie HCVA scores between the final measurements for the right and left eyes for exposed subjects (n = 43). The results indicated that the *M* for the measurement for the right eye (*M* = 0.07 logMAR, *SD* = 0.11) was not statistically significantly different from the *M* for the left eye (*M* = 0.08 logMAR, *SD* = 0.12), with p = 0.67.

Bailey-Lovie low contrast visual acuity

A paired-samples *t*-test was conducted to evaluate whether there was a significant difference in Bailey-Lovie LCVA scores between the final measurements for the right and left eyes for exposed subjects (n = 43). The results indicated that the *M* for the measurement for the right eye (*M* = 0.30 logMAR, *SD* = 0.12) was not statistically significantly different from the *M* for the left eye (*M* = 0.30 logMAR, *SD* = 0.13), with p = 0.83.

Small letter contrast sensitivity

The measured data value is the total number of incorrect (unreadable) letters. Each score is converted into a meaningful value of logCS using the formula logCS = 1.3 – N*(0.01), where N is the total number of missed letters. The *M* expected score on this test is logCS = 1.1.

A paired-samples *t*-test was conducted to evaluate whether there was a significant difference in SLCT scores between the final measurements for the right and left eyes for exposed subjects (n = 43). The results indicated that the *M* for the measurement for the right eye (*M* = 01.02 logCS, *SD* = 0.24) was not statistically significantly different from the *M* for the left eye (*M* = 1.04 logCS, *SD* = 0.21), with p = 0.67.

Color perception

The Lanthony (1986) desaturated D-15 hue test, adapted from the Farnsworth (1947) Panel D-15 test, was used to measure color vision. In order to compare small differences in performance, a modified Farnsworth-Munsell (1943) FM-100 test quantitative perception scoring scheme was used. The Panel D-15 total TES was calculated using the calculation proposed by Lanthony (1986). Scoring was performed using a web-based computer program designed for analyzing the Lanthony desaturated D-15 hue test (Torok, 2011). A second metric calculated from the D-15 test was the CCI, a measure the severity of the color deficit.

Paired-samples *t*-tests was conducted to evaluate whether there was a significant difference in TES and CCI scores between the final measurements for the right and left eyes for exposed subjects (n = 46). The results indicated that the means for both the TES and CCI measurements for the right eye (TES *M* = 6.83; CCI *M* = 1.18) were not statistically significantly different from the means for the left eye (TES *M* = 4.80; CCI *M* = 1.13), with p = 0.12 and p = 0.17, respectively.

Accommodation

When the change in accommodative power for the left and right eyes of exposed subjects (n = 46) was analyzed, statistically significant differences in accommodative power (in diopters) between the first and last measured values for each eye were found. For the right eye, the *M* for the *first* measurement was 7.2D (*SD* = 2.5) vs. the *M* for the *last* measurement, which was 5.3D (*SD* = 1.9), (p = < 0.000). Similarly, for the left eye, the first measurements (M = 7.93, *SD* = 2.6) also were statistically significantly different from the last measurements (M = 5.5, *SD* = 2.0), p = < 0.000.

The *M* exposure time between exposed subjects' first and last measurements was 4.0 years, and the *M* age of the exposed subjects at the final measurement was 38.1 years. The *M* change in accommodative power across both eyes was approximately -1.8D. It is well known that the amplitude of accommodation declines with age to less than 2D by the time a person reaches 45 to 50 years of age. Therefore, the statistically significant differences found above are not surprising.

For this reason, an alternate analysis was conducted using the changes in accommodative power for the right and left eyes. A paired t-test was performed on the differences between first and final values for the right (M = -1.85D) and left (M = -1.80) eyes was not found to be significant (p = 0.76).

Eye preference

Of the 46 exposed subjects for whom eye preference (dominance) data were available for at least two exams, 38 subjects (83%) were measured as having the same (consistent) eye preference. An additional seven subjects (15%) were inconsistent in measured preference, in most cases alternating between right and left. Only one subject (2%) was found to have switched dominant eye, having been measured as having right eye preference for three exams and then left eye preference for the next three exams. However, this same subject overwhelmingly reported his right eye as his preferred eye for sighting and for the monocular tasks viewing through a telescope and through a keyhole (Questions 17 to 19 in the annual questionnaires).

Discussion and conclusions

The original study design called for a projection of 80 exposed and 300 control subjects by the midpoint (end of fifth year) of the study. Due to unanticipated military actions, study enrollment fell short of these goals. Only a total of 227 subjects were recruited for the study. However, due to a number of factors (e.g., subject combat deployments, geographical restraints on accessing subjects for examinations, and higher than expected subject retirements), only 116 subjects (46 exposed and 70 control subjects) achieved sufficient number of visual performance exams to be included in the final study analysis presented herein. The exposed group of 46 subjects included 11 subjects who were initially recruited as control subjects but converted to exposed subjects following completion of additional flight training in the Apache AH Mk 1 aircraft.

The 46 exposed subjects used in the final analysis were all male (100%) and ranged in age (at first exam date) from 23 to 47 years, with a *M* and *Mdn* of 34 and 35 years, respectively. The 70 control subjects were predominantly male (96%) and ranged in age (at first exam date) from 22 to 49 years, with a *M* and *Mdn* of 31 and 29 years, respectively. The difference between the exposed and control *M* age was found to be statistically significant ($p = 0.007$). The trend of slightly higher *M* (34 years for exposed subjects versus 31 years for control subjects) and *Mdn* ages (35 years for exposed subjects, versus 29 years for control subjects), reflects the fact that most of the pilots selected for initial transition into the Apache were older, more experienced pilots.

Flight hour data were reported by subjects on the annual questionnaire. Unfortunately, due to geographical challenges associated with deployments, there was not always a one-to-one correspondence between questionnaires and eye exams. Corresponding questionnaires were not obtained for 19% of control subjects' and 27% of exposed subjects' eye exams; and not all flight data were reported on the questionnaires. However, for some subjects, flight hour data could be extrapolated if a final questionnaire was available. As a result, flight hour data were underreported for 21% of control subjects and 17% of exposed subjects.

Flight experience (as measured by total flight hours) upon enrollment into the study was quite different for the two groups. Total flight hours reported by control subjects ranged from 80 to 7,400, with a *M* of 898. For exposed subjects, total flight hours (upon enrollment into study) ranged from 220 to 4,850, with a *M* of 2,405. The greater flight experience for the exposed group again is due to the fact that most of the pilots selected for initial transition into the Apache were older, more experienced pilots.

However, flight hours flown by the two groups during the study were fairly equal (*M* of 597 hours for control subjects vs. 584 hours for exposed subjects). As a group, control subjects accumulated a total of at least 26,862 flight hours during participation in the study. The exposed group accumulated a total of at least 21,184 flight hours during participation in the study.

Of concern is the lack of congruence between NVD flight hours reported by the two groups during participation in the study. These data were not available for years when questionnaires were not completed. In general, since the Apache is flown primarily using the IHADSS NVD, IHADSS usage hours track total flight hours. This is not necessarily true for non-Apache pilot NVG usage. As a result, NVG usage hours are most likely underreported. Only 2713 NVG hours could be confirmed vs. 21,892 IHADSS usage hours.

Vision problems

Previous studies have documented a number of visual problems associated with NVDs, both NVGs and IHADSS. The current study continued this trend, with headache, disorientation, and visual discomfort being common complaints. Headache was the most commonly reported symptom by both exposed and control subjects. For control subjects, headache was reported by approximately half of all subjects both *during* and *after* flight; disorientation (60%) was the most frequently reported symptom *during* flight for control subjects but was considerably less (36%) for exposed subjects. For exposed subjects, headache was the most frequently reported symptom

both *during* and *after* flight, with visual discomfort ranked second for both *during* and *after* flight. For headaches, no statistically significant differences were found either *during* ($p = 0.61$) or *after* ($p = 1.00$) flight. However, the greater frequencies reported *during* flight of disorientation symptoms for control subjects and visual discomfort symptoms for exposed subjects were found to be significant ($p = 0.03$ and $p = 0.01$, respectively). These findings are not surprising as disorientation has consistently been associated with NVG usage; correspondingly, visual discomfort frequently has been linked to the monocular design of the IHADSS.

With monocular HMDs (i.e., the IHADSS), a more complex visual situation is presented to the pilot. Since only one eye views the display, the brightness difference between the images presented to the two eyes can be quite large. While the other binocular alignment problems are not present, perceptual issues relating to conflicting left- and right-eye images can cause eye fatigue and disorientation. The major of these issues is binocular rivalry (Rash, Verona and Crowley, 1990). The response to one eye viewing the monochromatic green video image and the other eye viewing a dark cockpit and the outside world can be suppression of the eye viewing the dimmer cockpit and outside world. Viewing these dissimilar images has proven to be especially fatiguing during lengthy missions. Voluntary switching between the two images has been reported as difficult by some aviators. In addition, these competing images can lead to involuntary switching of attention, due to binocular rivalry (Melzer and Moffitt, 1997). However, there also was no significant difference found in self-reported eye fatigue between the two groups ($p = 0.30$).

Eye examination (Between-subject)

Over the course of the 10-year study, a total 351 eye exams were conducted: 152 exposed and 199 control subjects. More exams were conducted during the first 5 years of the study than in the later 5 years. This was a result of effects of the issues of retirements, geographically dispersed subject populations, and unanticipated and prolonged military actions in Iraq and Afghanistan.

The eye examination data show no statistically significant differences between exposed and control groups for any of the visual tests: *M* refractive error, high and low contrast visual acuity, small letter contrast, depth perception, color perception, accommodative power, near and far eye muscle balance, and eye dominance.

However, for the test parameters of accommodation and eye dominance, two minor differences warrant mention and explanation. For binocular accommodation examined by decade of age (based on age at last exam), a significant finding ($p = 0.04$) was present for the 20 to 29 year decade group. Fourteen control subjects (26 to 29 years of age) had a *M* accommodation of 7.5D; three exposed subjects (28 to 29 years of age) had a *M* accommodation of 9.1D. An examination of individual data values failed to show any outliers or other possible explanations. For the purpose of this study, the 1.6D of difference is being interpreted as a statistical anomaly associated with the small sample of three subjects in the exposed group.

Eye examination (Within-subject)

The primary objective of this study was to investigate whether or not long-term use of the monocular IHADSS HMD is degrading visual function of Apache pilots, primarily binocular performance. While the between-subject data analyses failed to show any statistically significant differences, additional within-subject analyses were conducted comparing right and left eye performance of exposed subjects. Not surprisingly, these additional analyses failed to identify any new significant concerns.

The only exception is for eye dominance. One exposed subject was measured as having switched dominant eye from left to right during participation in the study, based on the Dolman method "hole test" for eye dominance (Cheng et al., 2004). This subject was measured as left-eye dominant for the first 3 years of participation and as right-eye dominant for a subsequent 3 years of participation. Interestingly, this subject self-reported his right eye as his preferred eye in all annual questionnaires. While striking in the pattern of change for this subject, 20% of control subjects and 17% of exposed subjects were measured as having inconsistent dominant eye determinations during their participation in the study.

Eye dominance is difficult to objectively measure, and results of ocular dominance tests seem to vary depending on both the testing distance and the specific activity performed as part of the testing procedure (Rice et al., 2008). The optimum method for evaluating ocular dominance remains a topic of controversy among vision scientists. Therefore, the reversal of measured eye dominance by the hole test for this subject is not considered of consequence.

Summary

In summary, the study failed to find any statistically significant evidence that the prolonged use of the monocular IHADSS HMD produces any meaningful differential vision changes between the two eyes or that the visual performance of exposed subjects differed from the performance of control subjects.

Recommendations

In hindsight, the 10-year period of the study was too lengthy for studying a military aviation cohort. The hope of retaining pilots for that long of a period was overly ambitious. The original study design anticipated a minimum of 80 exposed and 300 control subjects by the midpoint (end of 5th year) of the study. This goal was not achieved. Across the full study, exposed subjects participated in the study for a *M* period of approximately 3.6 years (43 months). Control subjects had a comparable *M* period of participation of 3.8 years (45 months). Factors that influenced subject recruitment and retention included delays in the initial fielding of the AH Mk 1 Apache aircraft, the inclusion of junior officers (who have short flying careers), retirements, geographically dispersed subject populations, and unanticipated and prolonged military actions in Iraq and Afghanistan. While the occurrences of military actions could not be expected to be anticipated, their impact and the impact of the other factors could have been mitigated by a shorter study period. Although longitudinal studies, by their design, involve repeated

observations of the same subjects that are conducted over long periods of time, thereby making observing changes more accurate, the nature of the military aviation community introduces many obstacles to long-term study. Therefore, it is recommended that future studies of this type consider shorter periods of observation that can accommodate the challenges of this community.

After the various issues impacting subject retention, the next factor having the greatest impact on the study was the inability to achieve a high subject compliance with completion and submission of the annual questionnaire. The questionnaire was overly ambitious and consisted of 82 multi-part questions addressing flight experience, vision history, disorientation, neck and back pain, helmet usage, contact lens use, and handedness. To minimize its impact on subject time resources, the distribution and collection of the questionnaires were handled independently from the annual expanded vision exam. As a result, many subjects failed to consistently provide questionnaires to match the annual vision exams. Consequently, important correlated data were failed to be collected. The most important of these data were those of flight experience. This resulted in an underreporting of flight hours. While it was important to subject recruitment and retention that the time requirements of the study on subject schedules be minimized, subjects who reported for their vision exam without having submitted their corresponding questionnaire should have been asked to complete one at that time.

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Appendix A.

Subject consent form.

SUBJECT CONSENT FORM

The Effect of a Monocular Helmet-Mounted Display Aircrew Health: A Cohort Study of WAH-64 Pilots

I, **......................,** consent to participate in the scientific research programme titled 'The Effect of a Monocular Helmet-Mounted Display on Aircrew Health: A Cohort Study of WAH-64 Pilots', principal investigator Col. Malcolm G. Braithwaite, Consultant Adviser in Aviation Medicine, HQ DAAvn, Middle Wallop, Tel.: 01980-67-4367.

The DMSCRC has given scientific and ethical approval to this study and can be contacted at: Royal Defence Medical College, Horton Block, Fort Blockhouse, Gosport HANTS PO12 2AB, Tel.: 02392-765644.

Purpose of the study. The purpose of this study is to determine if the intermittent use of a monocular helmet-mounted display for attack helicopter flying has any long-term effect on visual performance. In plain terms, we are studying the effect of the WAH-64 Apache helmet-mounted display or helmet display unit (HDU) on the vision of Apache pilots. Since the Apache has been in service in the USA, there have been reports from US Army aircrew regarding visual symptoms including eyestrain, double vision, color vision changes, as well as other non-visual effects including back pain. These symptoms tend to improve with increasing experience and training, and according to US reports, are not a significant operational issue. Nonetheless, our duty of care compels us to document any aircraft-related health effects as completely as possible.

Conduct of the study. I understand that if I am a WAH-64 pilot, I am being recruited as a "research subject," and that my data will be used to detect any changes in my vision and general health related to the WAH-64. If I fly aircraft other than the WAH-64, I am being recruited as a "control subject," and my data will be used for comparison.

Both groups of subjects (research and control) will be asked to take a number of tests of visual function at the time of the annual aircrew medical examination. Some of these tests are not currently included in the annual aircrew medical examination. I understand that I will be asked to complete a questionnaire at the time of enrollment into the study and at each the annual aircrew medical examination. Sometime during each year, a research team will visit most Army aviation bases with a machine called an autorefractor, which determines the focusing strength of the eyes. When the research team visits my location, I understand that I will be asked to undergo this test.

All data collected for the purpose of this study will be treated as medical in confidence and is subject to the Data Protection Act and subsequent statutory instruments.

Hazards and Precautions. The tests of visual function involved in this research project are without risk or discomfort, and similar or identical tests are part of the existing annual aircrew medical examination. I understand that there is a small increased risk of medical disqualification

as a consequence of this study, simply because of the increased number of medical tests. However, this is very unlikely for the following reasons:

a) The additional tests involved in this study generally measure the same things as tests included in the current aircrew medical examination,

b) Standards do not exist for most of the tests involved in this study (if there are no pass/fail standards set for a test, the test cannot be failed).

c) Even if a medical condition is detected, it is unlikely that it will result in loss of my aircrew medical category.

I understand that there are virtually no hazards or risks involved in this study, and that, therefore, there are no related precautions. The risks and procedures as detailed above have been explained to me. I understand that acceptance of these risks does not take away my right to legal redress and possible compensation.

I fully understand that I may withdraw from the study at any time by notifying one of the research staff or the Specialist in Aviation Medicine / flight surgeon / doctor performing my annual aircrew medical and that I will suffer no penalty as a result. I realise that I am under no obligation to give the reason for my withdrawal or attend again for this or any other experimentation.

I acknowledge that I have received a copy of this consent form for my records.

Name of Subject .... Date ....

Signature of Subject ....

Name of Witness .... Date ....

Signature of Witness ....

Appendix B.

Demographic form.

Date questionnaire completed: ____________(YYMMDD)

Name: ____________________________________
(Surname, First Name, other initials)

Service number: __________________

Date of birth: ________(YYMMDD)

Present age: ________yrs

Gender: [ ] male [ ] female

When did you join the Army?: _____________

Current Unit: _____________________

Present employment:

Pilot QHI Other (Please specify)

AIRCRAFT CURRENTLY FLOWN (CIRCLE 1 OR MORE)

Lynx Gazelle A109 Bell 212 Islander Other (Please specify) _____________

AVIATION EXPERIENCE

Which year did you gain your wings?: ________

Appendix C.

Eye exam data record form.

Subject Eye Exam Record Form

Date: ___________________________
Subject number: ___________________ Rank: ________
Administrator: ____________________
Location: _________________________

Test 1a: Bailey-Lovie High Contrast Visual Acuity
Total number missed for:
Right eye: _______ Left eye: _______

Test 1b: Bailey-Lovie Low Contrast Visual Acuity
Total number missed for:
Right eye: _______ Left eye: _______

Test 2: Small Letter Contrast
Total number missed for:
Right eye: _______ Left eye: _______

Test 3: Depth Perception
Minimum angle of stereopsis _______

Test 4:Color Perception
Right eye:
___ No reversal

__ __ __ __ __ __ __ __ __ __ __ __ __ __ __
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Left eye:
___ No reversal

__ __ __ __ __ __ __ __ __ __ __ __ __ __ __
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Test 5: Accommodation

Without spectacles	With spectacles
Both eyes: ___ cm	Both eyes: ___ cm
Right eye: ___ cm Left eye: ___	Right eye: ___ cm Left eye: ___

Test 6: Eye muscle balance
Distance
Orthophoria: ___Yes ____No
Heterophoria: Esophoria____ Exophoria____
Hyperphoria: Right eye____ Left eye_____

Near
Orthophoria: ___Yes ____No
Heterophoria: Esophoria____ Exophoria____
Hyperphoria: Right eye____ Left eye_____

Test 7: Eye Preference
Right eye____ Left eye_____

Additional Comments: ____

Appendix D.

Non-Apache (Control) subject annual questionnaire.

[*For comparison purposes with the Apache (Exposed) questionnaire, some question numbers have been deliberately omitted in this questionnaire]*

Date questionnaire completed: _____________

Subject #: ______________________________

1. Present employment: Tick one only

Line Pilot [ ]
QHI [ ]
Other (Please specify) [ ]
____

5b. Aircraft currently flown (Circle 1 or more)

Lynx Gazelle A109 Bell 212 Islander Other (Please specify)__________________

Flying hours

6a. Total flight hours (rounded to nearest 10): ______

6b. Total flight hours in last year (rounded to nearest 10): _____

6c. Total flight hours in last 8 weeks (exact): _____

8a. Are you NVG current? (Tick one only)

Yes [ ]
No [ ]

8b. If YES, what category? (Circle one only) 1 2 3

9. Please give approximate number of NVG hours

9a. Total NVG hours _____________

9b. In the last year: _____________

9c. In last 8 weeks _____________

Vision History

10a. Have you ever been prescribed spectacles? (Tick one only)

YES [ ]
NO [ ]

10b. If YES, please give reason for spectacles (For example, for distance, for reading/close work, all the time, flying only):

____

____

10c. Age when spectacles were first prescribed: _____________

10d. Date of most recent prescription: ____________________

11. Have you ever worn contact lenses? (Tick one only)

Never [ ]
Discontinued wear [ ]
Presently wear [ ]

If discontinued contact lenses within last year or presently using, please fill out the supplemental form (appendix 1 to annex D) for contact lens users.

12a. Do you use the **corrective flying spectacles (CFS)** with NVGs? (Tick one only)

YES [ ]
NO [ ]

12b. If YES, do the CFS interfere with your ability to use the NVG?

YES [ ]
NO [ ]

12c. If YES, please explain:

____

13. If you do require spectacles for flying, but do **NOT** use the CSF or contact lenses, do you experience any difficulty:

a. When viewing cockpit instruments?

YES [ ]
NO [ ]

b. If YES, please explain:

____

____

c. When viewing outside the cockpit?

YES [ ]
NO [ ]

d. If YES, please explain:

____

____

14a. Have you ever been treated for an eye disease or an eye injury?

YES [ ]
NO [ ]

14b. If YES, please state when, for what reason, and do you have any continuing problems?

____

____

15. Do you get headaches from extended periods of close work (For example, reading small print)?

YES [ ]
NO [ ]

16. Do you ever experience eye-strain?

YES [ ]
NO [ ]

17. Which is your preferred sighting eye? (Tick one only)

Left	[ ]
Right	[ ]
Equal	[ ]
Don't know	[ ]

18. Which eye would you use with a telescope?

Left	[ ]
Right	[ ]
Equal	[ ]

19. Which eye would you use to see through a keyhole?

Left	[ ]
Right	[ ]
Equal	[ ]

21. <u>**While flying**</u>, have you experienced (Tick one box on each row **only**):

If other than never, please comment on how often, duration of symptoms, severity of symptoms and impact on that flight.

a. Visual discomfort: Never [ ] Sometimes [ ] Always [ ]

Comment:____

b. Headache: Never [ ] Sometimes [ ] Always [ ]

Comment:____

c. Double vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

d. Blurred vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

e. After Images: Never [ ] Sometimes [ ] Always [ ]

Comment:____

f. Disorientation: Never [ ] Sometimes [ ] Always [ ]

Comment:____

g. Dizziness: Never [ ] Sometimes [ ] Always [ ]

Comment:____

h. Nausea: Never [ ] Sometimes [ ] Always [ ]

Comment:____

22. **After flying**, have you experienced (Tick one box on each row **only**):

If other than never, please comment on how often, how long post flight before symptoms began, duration of symptoms, and severity of symptoms:

a. Visual discomfort: Never [ ] Sometimes [ ] Always [ ]

Comment:____

b. Headache: Never [ ] Sometimes [ ] Always [ ]

Comment:____

c. Double vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

d. Blurred vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

e. After Images: Never [ ] Sometimes [ ] Always [ ]

Comment:____

f. Disorientation: Never [ ] Sometimes [ ] Always [ ]

Comment:____

g. Dizziness: Never [ ] Sometimes [ ] Always [ ]

Comment:____

h. Nausea: Never [ ] Sometimes [ ] Always [ ]

Comment:____

i. Unsteadiness or trouble with balance:

Never [ ] Sometimes [ ] Always [ ]

23-24. Not asked of non-Apache Pilots

25a. To what extent does flying using NVG cause eye fatigue?

Not at all	[ ]
To a slight extent	[ ]
To a moderate extent	[ ]
To a great extent	[ ]

26. How do you use your visor? (not the Face Protective Visor) (Tick one on each row ONLY)

a.	Day:	UP	[ ]	DOWN	[ ]
b.	Night:	UP	[ ]	DOWN	[ ]

26a. If either answer is “UP”, please explain why.

____

29a. **After** using the NVG, do you experience a difference in the appearance of colors?

YES	[ ]
NO	[ ]

29b. If YES, please describe what seems different:

____

29c. If YES, how long does this effect last? (Tick one only)

<15 minutes post flight	[ ]
15 – 60 minutes post flight	[ ]
1 – 2 hours post flight	[ ]
2 – 4 hours post flight	[ ]
Greater than 4 hours post flight	[ ]

30a. Have you ever experience symptoms of faintness, greying or loss of vision of any kind during periods of “aggressive” flying?

YES [ ]
NO [ ]

30b. If YES, were you flying the aircraft at the time?
YES [ ]
NO [ ]

Describe the symptoms, their severity and duration, and the flight profile at the time of the incident.

____

____

Disorientation

The definition of Spatial Disorientation (SD) used in the United Kingdom is as follows:

A failure to perceive correctly one’s position, motion or attitude with respect to the earth’s surface (horizontal reference) or the acceleration due to gravity (vertical reference).

It is **NOT** getting lost - that is **geographical** disorientation.

32a. Have you ever experienced any SD problems while using NVG?

YES [ ]
NO [ ]

32b. If YES, please explain the situation and cause. Include degree of SD with a description:

____
____
____

Neck Pain

For the purposes of this survey, **neck pain** is pain **ABOVE (but not including) the level of the shoulder blades. THERE ARE SEPARATE QUESTIONS ON NECK PAIN DURING AND AFTER FLIGHT.**

40. <u>Neck pain **DURING** flight</u>

a. Have you ever experienced neck pain **<u>during</u>** a flight?

YES	[ ]
NO	[ ]

b. If you have experienced neck pain **<u>during</u>** flight, how long into the flight were you before the pain began? _______ minutes

c. Please indicate the **total number** of episodes of neck pain you have experienced **<u>during</u>** flight. (Tick one box only)

1-3	[ ]
4-10	[ ]
10+	[ ]

d. How many episodes of neck pain **<u>during flight</u>** have you had in the last year?___

e. In which aircraft have you experienced your **most frequent** neck pain (Circle 1 or more)

Lynx Gazelle A109 Bell 212 Islander Other (Please specify) _____________

f. Where is the **main site** of your neck pain? (Tick one only)

Left side of the neck	[ ]
Right side of the neck	[ ]
Centre of the neck	[ ]

g. Which of the following factors resulted in your neck pain **<u>during</u>** flight?

Without NVGs	[ ]	
With NVGs	[ ]	
Other (Please specify)	[ ]	_______

h. Indicate if any of the following factors may have influenced your neck pain **<u>during</u>** flight:

Being a student pilot	[ ]	
Being a QHI	[ ]	
Infrequent flying duties	[ ]	
Recent illness/injury	[ ]	
Mission type (Please specify)	[ ]	_________

41. <u>Neck pain **AFTER** flight</u>

a. Have you ever experienced neck pain **<u>after</u>** a flight?

YES	[ ]
NO	[ ]

b. If you have experienced neck pain **<u>after</u>** flight, how long into the flight were you before the pain began? _______ minutes

c. Please indicate the **total number** of episodes of neck pain you have experienced **<u>after</u>** flight. (Tick one box only)

1-3	[ ]
4-10	[ ]
10+	[ ]

d. How many episodes of neck pain **<u>after flight</u>** have you had in the last year?_____

e. Which of the following factors resulted in your neck pain **<u>after</u>** flight?

Without NVGs	[ ]
With NVGs	[ ]
Other (Please specify)	[ ] ___________

f. Indicate if any of the following factors may have influenced your neck pain **<u>after</u>** flight:

Being a student pilot	[ ]
Being a QHI	[ ]
Infrequent flying duties	[ ]
Recent illness/injury	[ ]
Mission type (Please specify)	[ ] _____

42. Indicate the severity of neck pain, for the **<u>worst</u>** episode of pain experience during flight and after flight.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

43. If you **COMMONLY** experience neck pain, please indicate an **average** severity of pain experienced.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

44. How long did the symptoms persist for the **worst** episode of neck pain?

During flight only [ ]
Less than 2 hrs after flight [ ]
2-11 hours after flight [ ]
12-24 hours after flight [ ]
1-4 days after flight [ ]
more than 4 days after flight [ ]

45. How long do the symptoms usually persist for the **average** episode of neck pain?

During flight only [ ]
Less than 2 hrs after flight [ ]
2-11 hours after flight [ ]
12-24 hours after flight [ ]
1-4 days after flight [ ]
More than 4 days after flight [ ]

46a. Have your ever sought treatment for flight related neck pain?

YES [ ]
NO [ ]

46b. If YES, was the treatment sought from:

Specialist in Aviation Medicine (SAM) [ ]
Military General Practitioner (GP) [ ]
Civilian GP [ ]
Physiotherapist [ ]
Osteopath [ ]
Chiropractor [ ]
Acupuncturist [ ]
Other (Please specify) [ ] ____________________________

46c. Were you given any treatment for your neck pain?

YES [ ]
NO [ ]

46d. If YES, please describe briefly the treatment you received:

____

____

46e. Have you ever taken any action in order to minimise or avoid flight-related neck pain?

YES [ ]
NO [ ]

If YES, please describe the type of action taken and if the action taken was effective:

____

47a. Have you ever been grounded as a result of flight-related neck pain?

YES [ ]
NO [ ]

47b. If YES, please indicate how long you were grounded:

< 1 week	[ ]
1-2 weeks	[ ]
3-4 weeks	[ ]
> 1 month	[ ]
Currently grounded	[ ]

<u>Back Pain</u>

For the purposes of this survey, **back pain** is pain **at or BELOW the level of the shoulder blades.**

THERE ARE SEPARATE QUESTIONS ON NECK PAIN <u>DURING</u> AND <u>AFTER</u> FLIGHT.

48. For which of the following reasons do you primarily adjust your seat? (Tick one only)

Optimum vision	[ ]
Optimum control position	[ ]
A compromise between these	[ ]
Other reasons (Please specify	[ ]

____

_49. With your seat in the normal position, and sitting in your normal flying posture with the harness inertia reel locked, how easily can you reach and fully operate the critical and emergency controls and switches?

Not problem	[ ]
Slight difficulty	[ ]
Moderate difficulty	[ ]
Cannot reach	[ ]

50. Have you had a previous back injury?

YES	[ ]
NO	[ ]

If YES please give the date and brief details: ________________________________

51. <u>Back pain **DURING** flight</u>

a. Have you ever experienced back pain **<u>during</u>** a flight?

YES	[ ]
NO	[ ]

b. If you have experienced back pain **<u>during</u>** flight, how long into the flight were you before the pain began? _______ minutes

c. Please indicate the total number of episodes of back pain you have experienced <u>during</u> flight:

1-3	[ ]
4-10	[ ]
+10	[ ]

d. How many episodes of back pain **<u>during flight</u>** have you had in the last year? ___

e. In which aircraft have you experienced your **most frequent** back pain (Circle 1 or more)

Lynx Gazelle A109 Bell 212 Islander Other (Please specify) ____________

f. Where is the **main site** of your back pain? (Tick one only)

Lower back	[ ]
Mid back	[ ]
Shoulders	[ ]
Other (please specify)	[ ] ________________________

g. Indicate if any of the following factors may have influenced your back pain **<u>during</u>**

flight:

Unsatisfactory seat position [ ] (Please explain below)

Length of flight [ ] (How long before pain began? _____ minutes)
Infrequent flying duties [ ]
Recent illness/injury [ ]
Mission type (Please explain) [ ]

---

52. Back pain **AFTER** flight

a. Have you ever experienced back pain **after** a flight?

YES [ ]
NO [ ]

b. Please indicate the total number of episodes of back pain you have experienced **after** flight:

1-3 [ ]
4-10 [ ]
+10 [ ]

c. How many episodes of back pain **after flight** have you had in the last year? _____

d. Indicate if any of the following factors may have influenced your back pain **during** flight:

Unsatisfactory seat position [ ] (Please explain below)

Length of flight [ ] (How long before pain began? _____ minutes)
Infrequent flying duties [ ]
Recent illness/injury [ ]
Mission type (Please explain) [ ]

---

53. Indicate the severity of back pain, for the **worst** episode of pain experience during flight and after flight.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

54. If you **COMMONLY** experience back pain, please indicate an **<u>average</u>** severity of pain experienced.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

55. How long did the symptoms persist for the worst episode of back pain?

During flight only [ ]
less than 2 hrs after flight [ ]
2-11 hours after flight [ ]
12-24 hours after flight [ ]
1-4 days after flight [ ]
More than 4 days after flight [ ]

56. How long do the symptoms usually persist for the **<u>average</u>** episode of back pain?

During flight only [ ]
Less than 2 hrs after flight [ ]
2-11 hours after flight [ ]
12-24 hours after flight [ ]
1-4 days after flight [ ]
More than 4 days after flight [ ]

57a. Have your ever sought treatment for flight related back pain?

YES [ ]
NO [ ]

57b. If YES, was the treatment sought from:

Specialist in Aviation Medicine (SAM) [ ]
Military General Practitioner (GP) [ ]
Civilian GP [ ]

Physiotherapist [ ]
Osteopath [ ]
Chiropractor [ ]
Acupuncturist [ ]
Other (Please specify) [ ] ______________________

57c. Were you given any treatment for your back pain?

YES [ ]
NO [ ]

57d. If YES, please describe briefly the treatment you received:

____

____

57e. Have you ever taken any action in order to minimise or avoid flight-related back pain?

YES [ ]
NO [ ]

57f. If YES, please describe the type of action taken and if the action taken was effective:

____

____

58a. Have you ever been grounded as a result of flight-related back pain?

YES [ ]
NO [ ]

58b. If YES, please indicate how long you were grounded:

< 1 week [ ]
1-2 weeks [ ]
3-4 weeks [ ]
> 1 month [ ]
Currently grounded [ ]

59a. Do the standard procedures for adjusting the seat allow you to achieve a good flying position?

YES [ ]
NO [ ]

59b. If NO, explain any difficulties you have with the seat adjustment mechanism. Include any additional methods you use to improve your flying position:

____

____

60a. How would you rate the **overall comfort** of the seat on a scale of 1 to 9. _____

1 = extremely uncomfortable 5 = adequate 9 = extremely comfortable

60b. If there is any discomfort, what causes it?

____

Helmet Usage

61. What helmet size do you wear? (Tick one only)

SMALL	[ ]
MEDIUM	[ ]
MEDIUM LONG	[ ]
MEDIUM BROAD	[ ]
LARGE	[ ]

62a. Grade the quality current fit on a scale of 1 to 9. ________

1 = unsatisfactory 5 = adequate 9 = excellent

62b. If less than perfectly satisfied, please describe any problem the fit causes.

____

____

63a. Has your helmet been adjusted by anyone other than the Safety Equipment Section fitters?

YES	[ ]
NO	[ ]

63b. If YES, by whom?

SAM	[ ]
Self	[ ]
QHI	[ ]
Fellow pilot	[ ]
Manufacturer’s representative	[ ]

Other (Please specify) [ ] ___________________

65. Have you experienced any breakage, binding, slipping, or other malfunction with any of the following? (Circle one in each row)

Visors	No	Yes
Visor activators	No	Yes
Chinstrap	No	Yes
Suspension assembly	No	Yes
Microphone	No	Yes
Microphone Boom	No	Yes
Earcups	No	Yes
Helmet internal speakers	No	Yes
HDU mounting bracket	No	Yes
Communication cable	No	Yes
Electronics cable	No	Yes

Remarks:

____

____

68a. Have the NVG ever inadvertently released during flight?

YES [ ]
NO [ ]

68b. If YES, how many times has this happened? ____________

69a. Do you currently achieve a full field of view with the NVG?

YES [ ]
NO [ ]

69b. If NO, assess which items of information you are not seeing:______________________

71. Does the visor come down far enough? (not Face Protective Visor)

YES [ ]
NO [ ]

Remarks:

____

73. Does the visor rub your nose or face when extended?

YES [ ]
NO [ ]

Remarks:

74. Is the visor easily scratched?

YES [ ]
NO [ ]

Remarks:

75. How would you rate the **THERMAL** comfort of the helmet on a scale of 1 to 9 _______

1 = extremely uncomfortable 5 = adequate 9 = extremely comfortable

If there is any discomfort, what causes it?

76. How would you rate the **overall comfort** of the helmet on a scale of 1 to 9 __________

1 = extremely uncomfortable 5 = adequate 9 = extremely comfortable

If there is any discomfort, what causes it?

____

77. Do you feel that you currently need a different size helmet? (TICK ONE ONLY)

NO CHANGE [ ]
SMALLER [ ]
LARGER [ ]

78. How would you rate the **STABILITY** of the helmet on a scale of 1 to 9 _______________

1 = extremely unstable
5 = adequate
9 = extremely stable

If there is any instability, what causes it?

____

80. How would you rate the overall **noise protection** that you have experienced in flight on a scale of 1 to 9 _______________

1 = extremely noisy
5 = adequate
9 = extremely quiet

81. How would you rate the overall **quality of radio and intercom audio** that you have experienced in flight on a scale of 1 to 9 _______________

1 = extremely poor
5 = adequate
9 = extremely good

82. Are the capabilities of your current helmet sufficient to allow you to safely meet all mission requirements?

YES [ ]
NO [ ]

- -

If you would like to make additional comments on the capabilities or limitations of the IHADSS system, which have not been fully addressed by this survey, please do so below.

THANK YOU

Appendix E.

Apache (Exposed) subject annual questionnaire.

Date questionnaire completed: _____________

Date questionnaire completed: _____________

Subject #: ______________________________

1. Present employment: Tick one only

Converting onto WAH-64	[ ]
Line Pilot	[ ]
QHI	[ ]
Other (please specify)	[ ] ____

2. Month and Year in which you were WAH-64 qualified: _________

3a. In which crew position do you fly? Tick one only

Front seat	[ ]
Rear seat	[ ]
Both	[ ]

3b. If both, please estimate the percent of time you fly in each seat: Front ____ Rear ______

4. Primary aircraft prior to WAH-64: ___________________

5a. Do you **currently** fly aircraft **other** than WAH-64?

Yes [ ] No [ ]

5b. If YES, please specify (Circle one or more)

Lynx Gazelle A109 Bell 212 Islander Other (please specify) __________

<u>Flying Hours</u>

6a. Total flight hours (rounded to nearest 10): ______

6b. Total flight hours in last year (rounded to nearest 10): _____

6c. Total flight hours in last 8 weeks (exact): _____

<u>WAH-64 Flying Hours</u>

7a. Total WAH-64 flying hours (rounded to nearest 10): ______

7b Total WAH-64 flying hours in last year (rounded to nearest 10): _____

7c. Total WAH-64 flying hours in last 8 weeks (exact): _____

7d. Total WAH-64 flying hours in last year using IHADSS (exact): ______

7e. Total WAH-64 **simulator** hours in last year (rounded to nearest 10): _____
(include both FMS and FDS)

8a. Are you NVG current? (Tick one only)

Yes [ ] No [ ]

8b. If YES, what category? (Circle one only) 1 2 3

9. Please give approximate number of NVG hours

9a. Total NVG hours _____________

9b. In the last year: _____________

9c. In last 8 weeks _____________

Vision History

10a. Have you ever been prescribed spectacles? (Tick one only)

YES [ ] NO [ ]

10b. If YES, please give reason for spectacles (For example, for distance, for reading/close work, all the time, flying only):

____

____

10c. Age when spectacles were first prescribed: _____________

10d. Date of most recent prescription: ___________________

11. Have you ever worn contact lenses? (Tick one only)

Never [ ]
Discontinued wear [ ]
Presently wear [ ]

12a. Do you use the modified spectacles with the HMD? (Tick one only)

YES [ ] NO [ ]

12b. If YES, do the modified spectacles interfere with your ability to see the HMD symbology?

YES [ ] NO [ ]

12c. If YES, please explain:

____

12d. If you use modified spectacles, do you remove the right lens?

YES [ ] NO [ ]

13. If you do **require spectacles for flying, but do <u>NOT</u>** use the modified spectacles or contact lenses, do you experience any difficulty?

a. When viewing cockpit instruments?

YES [ ] NO [ ]

b. If YES, please explain:
____

c. When viewing outside the cockpit?

YES [ ] NO [ ]

d. If YES, please explain: ____
____

14a. Have you ever been treated for an eye disease or an eye injury?

YES [ ] NO [ ]

14b. If YES, please state when, for what reason, and do you have any continuing problems?
____
____

15. Do you get headaches from extended periods of close work (For example, reading small print)?

YES [ ] NO [ ]

16. Do you ever experience eye-strain?

YES [ ] NO [ ]

17. Which is your preferred sighting eye? (Tick one only)

Left [ ]
Right [ ]
Equal [ ]
Don't know [ ]

18. Which eye would you use with a telescope?

Left [ ]
Right [ ]
Equal [ ]

19. Which eye would you use to see through a keyhole?

Left	[ ]
Right	[ ]
Equal	[ ]

20. Is your preferred eye the same one as prior to WAH-64 training?

YES [ ] NO [ ]

21. **<u>While flying</u>** the WAH-64, have you experienced (tick one box on each row **only**):

If other than never, please comment on how often, duration of symptoms, severity of symptoms and impact on that flight.

a. Visual discomfort: Never [ ] Sometimes [ ] Always [ ]

Comment:____

b. Headache: Never [ ] Sometimes [ ] Always [ ]

Comment:____

c. Double vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

d. Blurred vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

e. After Images: Never [ ] Sometimes [ ] Always [ ]

Comment:____

f. Disorientation: Never [ ] Sometimes [ ] Always [ ]

Comment:____

g. Dizziness: Never [ ] Sometimes [ ] Always [ ]

Comment:____

h. Nausea: Never [ ] Sometimes [ ] Always [ ]

Comment:____

22. **After flying** the WAH-64, have you experienced (tick one box on each row **only**):

If other than never, please comment on how often, how long post flight before symptoms began, duration of symptoms, and severity of symptoms:

a. Visual discomfort: Never [ ] Sometimes [ ] Always [ ]

Comment:____

b. Headache: Never [ ] Sometimes [ ] Always [ ]

Comment:____

c. Double vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

d. Blurred vision: Never [ ] Sometimes [ ] Always [ ]

Comment:____

e. After Images: Never [ ] Sometimes [ ] Always [ ]

Comment:____

f. Disorientation: Never [ ] Sometimes [ ] Always [ ]

Comment:____

g. Dizziness: Never [ ] Sometimes [ ] Always [ ]

Comment:____

h. Nausea: Never [ ] Sometimes [ ] Always [ ]

Comment:____

i. Unsteadiness or trouble with balance:
Never [ ] Sometimes [ ] Always [ ]

Comment:____

23a. Have you noted any change in your ability to see or interpret the HMD symbology during any phase of flight?

YES [ ] NO [ ]

23b. If YES, please explain: ______________________________________

24. When viewing through the HMD, do you have difficulty focusing clearly on the external scene and symbology simultaneously?

Grade how frequently this affects you on a scale of 1 to 9. _________

1 = never 5 = 50% of the time 9 = always.

25. To what extent does flying by reference to the HDU cause eye fatigue?

a. At Night using PNVS/TADS (tick one box only)

Not at all	[ ]
To a slight extent	[ ]
To a moderate extent	[ ]
To a great extent	[ ]

b. During daytime flight using PNVS/TADS (tick one box only)

Not at all	[ ]
To a slight extent	[ ]
To a moderate extent	[ ]
To a great extent	[ ]

26. How do you use your visor? (tick one on each row ONLY)

a.	Day:	UP	[ ]	DOWN	[ ]
b.	Night:	UP	[ ]	DOWN	[ ]

26a. If either answer is "UP", please explain why.

____

27. **During** WAH-64 flight, does your vision sometimes unintentionally alternate between two eyes?

Grade how frequently this affects you on a scale of 1 to 9. _______________

1 = never 5 = 50% of the time 9 = always.

If other than never, please explain and estimate the duration.

____

28. **After** WAH-64 flight, does your vision sometimes unintentionally alternate between two eyes?
Grade how frequently this affects you on a scale of 1 to 9. _______________

1 = never 5 = 50% of the time 9 = always.

If other than never, please explain and estimate the duration.

____

29a. **After** using the IHADSS, do you experience a difference in the appearance of colors?

YES [ ] NO [ ]

29b. If YES, please describe what seems different:

____

29c. If YES, how long does this effect last? (Tick one only)

<15 minutes post flight [ ]
15 – 60 minutes post flight [ ]
1 – 2 hours post flight [ ]
2 – 4 hours post flight [ ]
Greater than 4 hours post flight [ ]

30a. Have you ever experience symptoms of faintness, greying or loss of vision of any kind during periods of "aggressive" flying?

YES [ ] NO [ ]

30b. If YES, were you flying the aircraft at the time?

YES [ ] NO [ ]

Describe the symptoms, their severity and duration, and the flight profile at the time of the incident.

____

Disorientation

The definition of Spatial Disorientation (SD) used in the United Kingdom is as follows:

A failure to perceive correctly one's position, motion or attitude with respect to the earth's surface (horizontal reference) or the acceleration due to gravity (vertical reference).

It is **NOT** getting lost - that is **geographical** disorientation.

31a. **During your conversion onto WAH-64**, did you ever experienced any SD problems while using the HDU?

YES [ ] NO [ ]

31b. If YES, please explain the situation and cause. Include degree of SD with a description:

____

____

32a. **As a line pilot**, have you ever experienced any SD problems while using the HDU? (please exclude SD during the conversion course)

YES [ ] NO [ ]

32b. If YES, please explain the situation and cause. Include degree of SD with a description:

____

____

33. When viewed through the HDU, do objects appear: (Please tick one)

Larger and closer than in reality? [ ]
Smaller and farther away than in reality? [ ]
About the right size and distance? [ ]

Any further comments:

____

____

34. To what extent have you experienced problems with time lags associated with the symbology that made it difficult to correlate the symbol movement with the aircraft movement, and thus required some degree of compensation to fly the aircraft? (Tick one box only.)

Not at all [ ]
To a slight extent [ ]
To a moderate extent [ ]
To a great extent [ ]

If other than not at all, for what symbols does this occur? Please explain:

____

____

35. To what extent have you experienced problems with the PNVS image lagging behind your head motion? (Tick one box only)

Not at all [ ]
To a slight extent [ ]
To a moderate extent [ ]
To a great extent [ ]

Please explain:

____

36. When looking through the HDU, how frequently do you have to switch your visual attention from the terrain to the flight symbology when acquiring flight information?

Grade how frequently on a scale of 1 to 9. _______________

1 = never 5 = 50% of the time 9 = always.

If other than never, please explain and estimate the duration.
____

37. During night flight operations, have you ever experienced a situation in which flashes of light occurring in the left visual field tend to "wash-out" the information being presented on the HDU to the right eye?

YES [ ] NO [ ]

If YES, please explain:
____

38. Does the difference between sensor location (on the nose of the aircraft) and eye location create problems with obstacle clearance (to the sides of the aircraft and below the aircraft)?

YES [ ] NO [ ]

If YES, under what conditions and manoeuvres do you most often experience this problem:
____
____

39. During long duration flights (over 2 hours), how often do you experience problems with the flight symbology "disappearing" from view due to fatigue?

Grade how frequently on a scale of 1 to 9. _______________

1 = never 5 = 50% of the time 9 = always.

If other than never, please explain including how you compensate for this problem:
____

Neck Pain

For the purposes of this survey, **neck pain** is pain **ABOVE (but not including) the level of the shoulder blades. THERE ARE SEPARATE QUESTIONS ON NECK PAIN DURING AND AFTER FLIGHT.**

40. Neck pain **DURING** flight

a. Have you ever experienced neck pain **during** a flight?

YES [ ] NO [ ]

b. If you have experienced neck pain **during** flight, how long into the flight were you before the pain began? _______ minutes

c. Please indicate the **total number** of episodes of neck pain you have experienced **during** flight. (Tick one box only)

1-3	[ ]
4-10	[ ]
10+	[ ]

d. How many episodes of neck pain **during flight** have you had in the last year?___

e. In which aircraft have you experienced your **most frequent** neck pain (circle 1 or more)

WAH-64 Lynx Gazelle A109 Bell 212 Islander Other (please specify) ____________

f. Where is the **main site** of your neck pain? (tick one only)

Left side of the neck	[ ]
Right side of the neck	[ ]
Centre of the neck	[ ]

g. Which of the following factors resulted in your neck pain **during** flight?

Without NVGs	[ ]
With NVGs	[ ]
IHADSS helmet without HDU	[ ]
IHADSS helmet with HDU	[ ]
Other (Please specify)	[ ] __________________

h. Indicate if any of the following factors may have influenced your neck pain **during** flight:

Being a student pilot	[ ]
Being a QHI	[ ]
Infrequent flying duties	[ ]

Recent illness/injury [ ]
Mission type (Please specify) [ ] _______________

41. <u>Neck pain **AFTER** flight</u>

a. Have you ever experienced neck pain **<u>after</u>** a flight?

YES [ ] NO [ ]

b. If you have experienced neck pain **<u>after</u>** flight, how long into the flight were you before the pain began? _______ minutes

c. Please indicate the **total number** of episodes of neck pain you have experienced **<u>after</u>** flight. (Tick one box only)

1-3 [ ]
4-10 [ ]
10+ [ ]

d. How many episodes of neck pain **<u>after flight</u>** have you had in the last year? ____

e. Which of the following factors resulted in your neck pain **<u>after</u>** flight?

Without NVGs [ ]
With NVGs [ ]
IHADSS helmet without HDU [ ]
IHADSS helmet with HDU [ ]
Other (Please specify) [ ] ____________________

f. Indicate if any of the following factors may have influenced your neck pain **<u>after</u>** flight:

Being a student pilot [ ]
Being a QHI [ ]
Infrequent flying duties [ ]
Recent illness/injury [ ]
Mission type (Please specify) [ ] _______________

42. Indicate the severity of neck pain, for the **<u>worst</u>** episode of pain experience during flight and after flight.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

44. If you **COMMONLY** experience neck pain, please indicate an **average** severity of pain experienced.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

44. How long did the symptoms persist for the **worst** episode of neck pain?

During flight only	[ ]
Less than 2 hrs after flight	[ ]
2-11 hours after flight	[ ]
12-24 hours after flight	[ ]
1-4 days after flight	[ ]
More than 4 days after flight	[ ]

45. How long do the symptoms usually persist for the **average** episode of neck pain?

During flight only	[ ]
Less than 2 hrs after flight	[ ]
2-11 hours after flight	[ ]
12-24 hours after flight	[ ]
1-4 days after flight	[ ]
More than 4 days after flight	[ ]

46a. Have your ever sought treatment for flight related neck pain?

YES [ ] NO [ ]

46b. If YES, was the treatment sought from:

Specialist in Aviation Medicine (SAM)	[ ]
Military General Practitioner (GP)	[ ]
Civilian GP	[ ]
Physiotherapist	[ ]
Osteopath	[ ]
Chiropractor	[ ]
Acupuncturist	[ ]
Other (Please specify)	[ ] _______________

46c. Were you given any treatment for your neck pain?

YES [ ] NO [ ]

46d. If YES, please describe briefly the treatment you received:

____

46e. Have you ever taken any action in order to minimise or avoid flight-related neck pain?

YES [ ] NO [ ]

If YES, please describe the type of action taken and if the action taken was effective:

____

47a. Have you ever been grounded as a result of flight-related neck pain?

YES [ ] NO [ ]

47b. If YES, please indicate how long you were grounded:

< 1 week	[ ]
1-2 weeks	[ ]
3-4 weeks	[ ]
> 1 month	[ ]
Currently grounded	[ ]

<u>Back Pain</u>

For the purposes of this survey, **back pain** is pain **at or BELOW the level of the shoulder blades THERE ARE SEPARATE QUESTIONS ON NECK PAIN <u>DURING</u> AND <u>AFTER</u> FLIGHT.**

48. For which of the following reasons do you primarily adjust your seat? (tick one only)

Optimum vision	[ ]
Optimum control position	[ ]
A compromise between these	[ ]
Other reasons (please specify	[ ]

____

49. With your seat in the normal position, and sitting in your normal flying posture with the harness inertia reel locked, how easily can you reach and fully operate the critical and emergency controls and switches?

Not problem	[ ]
Slight difficulty	[ ]
Moderate difficulty	[ ]
Cannot reach	[ ]

50. Have you had a previous back injury?

YES [ ] NO [ ]

If YES please give the date and brief details:

____

____

51. Back pain **DURING** flight

a. Have you ever experienced back pain **during** a flight?

YES [ ] NO [ ]

b. If you have experienced back pain **during** flight, how long into the flight were you before the pain began? _______ minutes

c. Please indicate the total number of episodes of back pain you have experienced during flight:

1-3 [ ]
4-10 [ ]
+10 [ ]

d. How many episodes of back pain **during flight** have you had in the last year? __

e. In which aircraft have you experienced your **most frequent** back pain (Circle 1 or more)

WAH-64 Lynx Gazelle A109 Bell 212 Islander Other (Please specify) _______

f. Where is the **main site** of your back pain? (Tick one only)

Lower back [ ]
Mid back [ ]
Shoulders [ ]
Other (Please specify) [ ]

g. Indicate if any of the following factors may have influenced your back pain **during** flight:

Unsatisfactory seat position [ ] (Please explain below)

____

Length of flight [ ] (How long before pain began? _____ minutes)
Infrequent flying duties [ ]
Recent illness/injury [ ]
Mission type [ ] (Please explain below)

____

52. <u>Back pain **AFTER** flight</u>

a. Have you ever experienced back pain **<u>after</u>** a flight?

YES [ ] NO [ ]

b. Please indicate the total number of episodes of back pain you have experienced **<u>after</u>** flight:

1-3 [ ]
4-10 [ ]
+10 [ ]

c. How many episodes of back pain **<u>after flight</u>** have you had in the last year? ____

d. Indicate if any of the following factors may have influenced your back pain **<u>during</u>** flight:

Unsatisfactory seat position [ ] (Please explain below)

____

Length of flight [ ] (How long <u>before pain began</u>? ____ minutes)
Infrequent flying duties [ ]
Recent illness/injury [ ]
Mission type [ ] (Please explain below)

____

53. Indicate the severity of back pain, for the **<u>worst</u>** episode of pain experience during flight and after flight.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

54. If you **COMMONLY** experience back pain, indicate an **<u>average</u>** severity of pain experienced.

Grade the severity on a scale of 1 to 9.

1 = no pain 9 = incapacitating (e.g. resulting in handing over control or aborting the mission)

DURING FLIGHT __________ **AFTER FLIGHT** __________

55. How long did the symptoms persist for the **<u>worst</u>** episode of back pain?

During flight only	[ ]
Less than 2 hrs after flight	[ ]
2-11 hours after flight	[ ]
12-24 hours after flight	[ ]
1-4 days after flight	[ ]
More than 4 days after flight	[ ]

56. How long do the symptoms usually persist for the **<u>average</u>** episode of back pain?

During flight only	[ ]
Less than 2 hrs after flight	[ ]
2-11 hours after flight	[ ]
12-24 hours after flight	[ ]
1-4 days after flight	[ ]
More than 4 days after flight	[ ]

57a. Have your ever sought treatment for flight related back pain?

YES [ ] NO [ ]

57b. If YES, was the treatment sought from:

Specialist in Aviation Medicine (SAM)	[ ]	
Military General Practitioner (GP)	[ ]	
Civilian GP	[ ]	
Physiotherapist	[ ]	
Osteopath	[ ]	
Chiropractor	[ ]	
Acupuncturist	[ ]	
Other (Please specify)	[ ]	________________________

57c. Were you given any treatment for your back pain?

YES [ ] NO [ ]

57d. If YES, please describe briefly the treatment you received:

____

____

57e. Have you ever taken any action in order to minimise or avoid flight-related back pain?

YES [ ] NO [ ]

57f. If YES, please describe the type of action taken and if the action taken was effective:

____

58a. Have you ever been grounded as a result of flight-related back pain?

YES [ ] NO [ ]

58b. If YES, please indicate how long you were grounded:

< 1 week	[ ]
1-2 weeks	[ ]
3-4 weeks	[ ]
> 1 month	[ ]
Currently grounded	[ ]

59a. Do the standard procedures for adjusting the seat allow you to achieve a good flying position?

YES [ ] NO [ ]

59b. If NO, explain any difficulties you have with the seat adjustment mechanism. Include any additional methods you use to improve your flying position:

____

60a. How would you rate the **overall** comfort of the seat on a scale of 1 to 9. ___________

1 = extremely uncomfortable 5 = adequate 9 = extremely comfortable

60b. If there is any discomfort, what causes it?

____

____

IHADSS Helmet Usage

61. What helmet size do you wear? (Tick one only.)

MEDIUM	[ ]
LARGE	[ ]
EXTRA LARGE	[ ]

62a. Grade the quality current fit on a scale of 1 to 9. ___________

1 = unsatisfactory 5 = adequate 9 = excellent

62b. If less than perfectly satisfied, please describe any problem the fit causes.

____

63a. Has your helmet been adjusted by anyone other than the Safety Equipment Section fitters?

YES [ ] NO [ ]

63b. If YES, by whom?

SAM	[ ]
Self	[ ]
QHI	[ ]
Fellow pilot	[ ]
Manufacturer's representative	[ ]
Other (Please specify)	[ ] ______________________

64a. Has the IHADSS suspension system rigid inner liner been modified in any manner? (Example: cut, ground, shaved, etc.)

YES [ ] NO [ ]

64b. If YES, please tick below: (More than one may apply.)

Front	[ ]
Back	[ ]
Top	[ ]
Bottom	[ ]
Left	[ ]
Right	[ ]

64c. If YES, by whom (no names)?

Safety Equipment Section fitters	[ ]
SAM	[ ]
Self	[ ]
QHI	[ ]
Fellow pilot	[ ]
Manufacturer's representative	[ ]
Other (Please specify)	[ ] ______________________

65. Have you experienced any breakage, binding, slipping, or other malfunction with any of the following? (Circle one in each row)

Visors	No	Yes
Visor activators	No	Yes
Chinstrap	No	Yes
Suspension assembly	No	Yes
Microphone	No	Yes
Microphone Boom	No	Yes
Earcups	No	Yes
Helmet internal speakers	No	Yes
HDU mounting bracket	No	Yes
Communication cable	No	Yes

Electronics cable No Yes

Remarks: ____

66. Have you experienced any discomfort while using the HDU?

YES [ ] NO [ ]

Remarks:

____

____

67. Have you experienced any difficulty installing or removing the HDU from the helmet?

YES [ ] NO [ ]

Remarks:

____

____

68a. Has the HDU ever inadvertently released during flight?

YES [ ] NO [ ]

68b. If YES, how many times has this happened? ____________

69a. Do you currently achieve a full field of view?

YES [ ] NO [ ]

69b. If NO, assess which items of information you are not seeing: ______________________

70. Was the custom trimming of the visor accurate and adequate?

YES [ ] NO [ ]

Remarks:

____

71. Does the visor come down far enough?

YES [ ] NO [ ]

Remarks:

____

72. Has the visor ever inadvertently retracted?

YES [ ] NO [ ]

Remarks:

____

73. Does the visor rub your nose or face when extended?

YES [ ] NO [ ]

Remarks:

____

74. Is the visor easily scratched?

YES [ ] NO [ ]

Remarks:

____

75a. How would you rate the **THERMAL** comfort of the IHADSS helmet on a scale of 1 to 9 __________

1 = extremely uncomfortable 5 = adequate 9 = extremely comfortable

75b. If there is any discomfort, what causes it?

____

76a. How would you rate the **overall** comfort of the IHADSS helmet on a scale of 1 to 9: ___

1 = extremely uncomfortable 5 = adequate 9 = extremely comfortable

76b. If there is any discomfort, what causes it?

____

77. Do you feel that you currently need a different size IHADSS helmet? (TICK ONE ONLY)

NO CHANGE [ ]
SMALLER [ ]
LARGER [ ]

78a. How would you rate the **STABILITY** of the IHADSS helmet on a scale of 1 to 9:______

1 = extremely unstable 5 = adequate 9 = extremely stable

78b. If there is any instability, what causes it?

____

79a. Have you had any problems boresighting the TADS?

YES [ ] NO [ ]

79b. If YES, what was the problem?

____

79c. What was done to correct the problem?

____

79d. Do you have any suggestions on how to better correct this problem?

____

80. How would you rate the overall **noise protection** that you have experienced in flight on a scale of 1 to 9: ______________

1 = extremely noisy 5 = adequate 9 = extremely quiet

81. How would you rate the overall **quality of radio and intercom audio** that you have experienced in flight on a scale of 1 to 9: _________

1 = extremely poor 5 = adequate 9 = extremely good

82. Are the capabilities of the IHADSS system sufficient to allow you to safely meet all mission requirements?

YES [ ] NO [ ]

- -

If you would like to make additional comments on the capabilities or limitations of the IHADSS system, which have not been fully addressed by this survey, please do so below.

THANK YOU

Appendix F.

Contact lens wearer's survey.

FOR CONTACT LENS USERS ONLY

Date questionnaire completed: _____________ Subject #: ______________________________

a. If contact lens wear was discontinued within the last year, please give the reason.
____

b. Please rate your experiences in inserting your lenses. (1-9)______
1 = No problems what-so-ever
5 = Minor problems
9 = Severe problems

c. Please rate your experiences in removing your lenses. (1-9)______
1 = No problems what-so-ever
5 = Minor problems
9 = Severe problems

d. In general, how comfortable are your contact lenses? (1-9)______
1 = Very comfortable
5 = Neither comfortable nor uncomfortable
9 = Very uncomfortable

e. How do you rate your vision with contact lenses as opposed to your vision with spectacles? (1-9)______
1 = Much better with contact lenses
5 = No difference between contact lenses and glasses
9 = Much better with glasses

f. Have you experienced any difficulty **maintaining** your contact lenses?

At home/in barracks	YES	NO
In the field	YES	NO

If YES, please explain: ____

g. Did any of the following weather conditions make the wearing of contact lenses difficult? (Check all that apply.)

_____ Hot weather	_____ Cold weather
_____ Wet weather	_____ Dry weather
_____ Sunny weather	_____ Windy weather
_____ Dusty conditions	_____ Other(explain)

h. Since your last contact lens review, have you experienced any of the following problems **while flying**? Tick only those that apply.

	FREQUENCY			
	Never	Rarely	Occasionally	Often
Eye irritation				
Eye pain				
Blurred vision				
Dry eye				
Light sensitivity				

i. If any of the above occurred, how bothersome was it?

	SEVERITY		
	Minor	Moderate	Severe
Eye irritation			
Eye pain			
Blurred vision			
Dry eye			
Light sensitivity			

j. Since your last contact lens review, did you experience any of the following problems **while on the ground**? Tick only those that apply.

	FREQUENCY			
	Never	Rarely	Occasionally	Often
Eye irritation				
Eye pain				
Blurred vision				
Dry eye				
Light sensitivity				

k. If any of the above occurred, how bothersome was it?

SEVERITY

	Minor	Moderate	Severe
Eye irritation			
Eye pain			
Blurred vision			
Dry eye			
Light sensitivity			

l. If you use contact lenses during flight, how would you rate their overall comfort?
(1-9) ____________
1 = unsatisfactory
5 = adequate
9 = excellent
Comments: ____

m. If you use contact lenses during flight, have difficulties with the lenses caused you to:
(Tick all that apply)

Reschedule or cancel flights	YES	NO
Deviate from flight plan	YES	NO
Hand over control in flight	YES	NO
Remove a lens in flight	YES	NO
Use eye drops in flight	YES	NO

If YES, please explain:
____

n. If this is your first year wearing lenses, please evaluate the training that you have received in the following aspects:

	Application	Removal
Ineffective	____________	__________
Poor	____________	__________
Fair	____________	__________
Good	____________	__________
Excellent	____________	__________

o. Overall, how would you rate the Army Aviation Medicine support of the contact lens programme?
(1-9)______
1 = Ineffective
5 = Fair
9 = Excellent

p. Finally, please comment on how the support for WAH-64 pilots who use contact lenses could be improved:

____

____

Appendix G.

The Edinburgh Handedness Inventory.

SUBJECT #:______________________

DATE:___________________________ (YYMMDD)

Please indicate your preferences in the use of hands in the following activities by putting a "+" in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put "++". If in any case you are really indifferent, put "+" in both columns.

Some of the activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted, is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all with the object or task.

TASK OR OBJECT	LEFT	RIGHT
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking match (match hand)		
10. Opening box (lid)		
Do not write below this line		
#R:___ - #L:___ =___/ (#R + #L) = ___ X 100 = EHI ___		

Appendix H.

List of acronyms.

AAC	Army Air Corps
ANVIS	Aviator's Night Vision Imaging System
CCI	Color Confusion Index
CFS	Corrective Flying Spectacles
CRT	cathode ray tube
CS	contrast sensitivity
D	diopter
DAAvn	Director of Army Aviation
DTIC	Defense Technical Information Center
EHI	Edinburgh Handedness Inventory
FLIR	forward-looking infrared
FOV	field of view
HCVA	high contrast visual acuity
HDU	helmet display unit
HMD	helmet-mounted display
HQ	Headquarters
IHADSS	Integrated Helmet and Display Sighting System
LCVC	low contrast visual acuity
MAR	minimum angle resolved
NVD	night vision device
NVG	night vision goggles
OD	Oculus Dexter (right eye); Doctor of Optometry
OS	Oculus Sinister (left eye)
PNVS	Pilot's Night Vision System
QHI	Qualified Helicopter Instructor
RAMC	Royal Army Medical Corps
SAM	Specialist in Aviation Medicine
SD	spatial disorientation
SLCT	small letter contrast test
TADS	Target Acquisition and Designation System
TES	Total Error Score
TTCP	The Technical Cooperative Program
USAARL	United States Army Aeromedical Research Laboratory

UNITED STATES ARMY
AEROMEDICAL RESEARCH LABORATORY

Department of the Army
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama, 36362-0577
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